EXTERNAL STRENGTHENING OF RC BEAMS USING *GIGANTOCHLOA LEVIS (BULUH BETING)* FIBER REINFORCED COMPOSITE PLATE

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ABSTRAK

Dalam pengajian semasa, penggunaan gentian buatan manusia merupakan kaedah yang cekap untuk megukuhkan struktur secara luaran. Namun begitu, kos pembuatan yang tinggi serta pencemaran alam sekitar telah meningkatkan kesedaran orang awam terhadap isu ini. Belakangan ini, gentian semula jadi telah menjadi bahan yang menarik perhatian penyelidik untuk menjalani kajian secara mendalami untuk mencungkil kemungkian menjadikan gentian semula jadi sebagai pengganti untuk gentian buatan manusia. Satu kajian telah dijalankan untuk mengkaji potensi penggunaan komposit yang diperbuat daripada gentian buluh dan matriks resin epoxy (BFRCP). Gentian buluh yang digunakan dalam kajian ini diperolehi daripada Raub, Pahang. Buluh mentah dan buluh kering telah dikaji dalam segi mekanikal dan fizikal. Kerja uji kaji yang dijalankan dalam segi mekanikal adalah ujian mampatan dan ujian tegangan. Selain itu, plat komposit telah diuji dalam segi mekanikal, iaitu ujian tegangan (ASTM D3039) dan ujian lenturan (ASTM D790-03). BFRCPs telah difabrikasi dengan nisbah isipadu gentian 0% dan 40%. Ujian empat mata titik beban telah dijalankan untuk mengkaji kelakuan rasuk konkrit bertetulangan yang mempunyai tetulang rangkai yang penuh dan tanpa tetulang rangkai di bahagian lentur rasuk. Berdasarkan hasil kaji, buluh kering mempunyai kekuatan mekanikal yang lebih tinggi berbanding dengan buluh mentah. Namun begitu, kekeringan buluh yang terlampau akan mengganggu kekuatan mekanikalnya. Manakala bagi kajian terhadap plat komposit. Kenaikan kekuatan tengangan sebanyak 374.59% bagi plat komposit bergentian dibanding dengan plat epoxy tulen. Manakala penambahbaikan plat bergentian sebanyak 750.60% dalam segi kekuatan lenturan berbanding dengan plat epoxy tulen. Berdasarkan hasil kajian daripada ujian empat mata titik beban, didapati rasuk konkrit tidak bertetulang yang tidak diperkuatkan (UNST) mempunyai kemerosotan kekuatan sebanyak 6.72% berbanding dengan rasuk konkrit yang mempunyai tetulang rangkai yang penuh. Di samping itu, rasuk konkrit tidak bertetulang yang diperkuatkan (ST) mempunyai kenaikan kekuatan sebanyak 9.30% dan 10.63% berbanding dengan UNST. Selain itu, rasuk yang diperkukuh mampu menampung kekuatan yang sama dengan rasuk yang mempunyai tetulang rangkai penuh. Dari segi retakkan rasuk, rasuk yang diperkukuhkan didapati mempunyai retak di bahagian pinggir plat komposit. Kesimpulannya, pengukuhan luaran rasuk konkrit bertetulangan dengan penggunaan buluh gentian – epoxy komposit didapati berkesan dan berpotensi menggantikan komposit gentian buatan manusia.

ABSTRACT

Synthetic fiber reinforced polymer (FRP) composite is an efficient method for strengthening of reinforced concrete (RC) externally. Unfortunately, the non-renewable, high cost production and environmental harmful of synthetic fibers had increased public awareness towards this issue and hence inevitable arisen the uses of renewable resources. A research had been conducted to investigate the potential of application of bamboo fiber reinforced composite plate (BFRCP) in external strengthening of RC beam. The bamboo fibers used was *Gigantochloa Levis*, also known as *Buluh Beting* which were obtained from Raub, Pahang. Mechanical behaviour of raw and dried bamboo was tested with compression and tensile tests. Besides, the composite plates with 0% and 40% fiber volume were tested for tensile test (ASTM D3039) and flexural test (ASTM D790-03) to identify the mechanical properties. Four-point loading test was conducted to investigate the structural behaviour of RC beams. Based on the result of the mechanical behaviour of bamboo, the dried bamboo showed higher mechanical strength as compared with the raw bamboo. However, the over-dried bamboo will affect the mechanical result. In terms of the composite behaviour, there was an increment of 374.59% of average ultimate tensile strength of fiber reinforced composite as compared to the un-reinforced composite. Whereas, for flexural test, the average ultimate strength of fiber reinforced composite was 11.76 times or 750.60% more than the neat epoxy sample. In terms of structural behavior, it was found that the un-strengthened beam without the shear link in the flexure zone (UNST) has shown a reduction in ultimate load of about 6.72% as compared to the control beam (CB). Whereas, two beams without the shear link in the flexure zone strengthened using BFRCP (ST) had an increment of 9.30% and 10.63% in terms of beam capacity as compared to beam UNST. Besides, both the strengthened beams, ST proven the capability to restore the load carrying capacity of the control beam. In terms of crack pattern, the BFRCP had diverted the cracks from the flexure zone to the edge of the plate for RC beam. Hence, this signifies that BFRCP has potential to be used as an alternative external strengthening material to the synthetic composite plate.

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LIST OF SYMBOLS

%	Percentage
mm	Millimetre
g/cm^3	Gram per centimetre cube
N	Newton
kN	Kilo Newton
ºC	Degree Celcius
g	Gram
mm^2	Millimetre square
MPa	Mega Pascal

LIST OF ABBREVIATIONS

ASTM	American standard testing manual
BFRCP	Bamboo fiber reinforced composite plate
BFRECP	Bamboo fiber reinforced epoxy composite plate
CNT	Carbon nanotube
FRP	Fiber Reinforced Polymer
LVDT	Linear variable displacement transducers
NaOH	Sodium hydroxide
NFRC	Natural fiber reinforced composite
RC	Reinforced concrete
UTM	Universal Testing Machine

CHAPTER 1

INTRODUCTION

1.1 Research Background

Fiber reinforced polymer (FRP) is a mixture of high strength fibers embedded in a polymer matrix to produce composite material. Commonly, synthetic fibers like carbon and glass are widely used in fabrication of FRP. The fibers are mainly contributing the mechanical properties, whereas polymer matrix responsible for the protection from environmental attack. The resultant composites are used in a range of industries including sporting, leisure, aerospace, automotive and construction (Gurunathan, Mohanty and Nayak, 2015). However, synthetic FRPs have problems in disposing as they do not decompose naturally in the ground. Owing to the fact that FRP had brought environment and sustainability issues, at a recent time, public attention has gone to green materials such as natural fibers as a resource in the field of polymer science through introduction of bio composites (Yildizhan, 2018). Bio-composites, also known as biodegradable composites is a sustainable material with eco-friendly natural fibers are used to replace the synthetic fibers. Moreover, bio-composites help to reduce raw material usage, reduce non-renewable waste as well as cut fossil-fuel consumption.

There are various types of natural fiber which included cellulose based, animal and mineral. For plant or cellulose based fiber, it is divided into different groups according to their function. Bamboo fiber was chosen as the filler because bamboo is a commonly found natural resource in Asia and South America. The mechanical properties of bamboo are relatively high and are comparable to those of wood. It has been traditionally used to build a variety of furniture and living tools. Furthermore, it takes only 6-8 months to grow to its mature size, whereas wood takes about 10 years. Fiber longitudinally aligned in its body provide high strength with respect to its weight which contribute the title of ‘natural glass fiber’(Okubo, Fujii and Yamamoto, 2004). The high cellulose content with moderate content of lignin approximately 32% and micro-fibrillar angle is relatively small which is 2°–10° contributed to the tensile strength and proportional to the modulus of elasticity. Hence bamboo fiber is suitable to be used as fiber reinforcement in different matrix (Tong *et al.*, 2017).

Matrix acts as the binding material which bind with fibers to form a composite plate. There are two types of matrix: thermoplastic and thermosetting. Thermoplastics are a plastic polymer material that changes properties when subjected to different temperature. Thermoplastics become soft when heat is applied and have a smooth, hard finish when cooled. It becomes moldable when exceeding a specific temperature and solidifies upon cooling. Meanwhile, thermosetting polymers are liquid state at room temperature prior curing. After undergoing heat treatment, it is in solid state and unable to re-hot deformable due to the difficulty in reforming. Most structural engineering applications used thermosetting plastics for applications as the thermosetting plastics are more advanced over thermoplastics if they are compared to both. Generally, thermosetting plastics are stronger than thermoplastic materials due to the strong covalent bonds between polymer chain that hard to break. Besides, thermosetting has a high crosslink density that provides a good thermal stability and resistance to chemical attack. Thermosetting that usually used for fabrication of composite plate are epoxy resin, vinyl ester resin and polyester resin (Chandra Das and Haque Nizam, 2014). Epoxy resin was used as the matrix to fabricate the bamboo fiber reinforced composite plate in this study.

Therefore, FRP has become more preferable to be used as the external strengthening material instead of rebuilding the structure. The low specific weight, low production cost and high strength of the natural FRP are the attractive features that may replace the synthetic FRP. Hence, retrofitting damaged structures by providing extra strengthening on it is the easiest and convenient method which helps to increase the service period of the structure.

1.2 Problem Statement

Over the last three decades, application of FRP is getting more popular, especially in the construction industry. The high strength-to-volume and high stiffness of synthetic reinforced fibers are the main reasons being chosen as the reinforced fibers (Dong, Wang and Guan, 2013). However, the cost of fabrication of synthetic fiber reinforced composite plate is much higher compared to the natural fiber reinforced composite plate. Moreover, the main drawback of synthetic reinforced composite plate is non-biodegradable properties which bring a serious adverse effect on the environment.

Non-renewable resources are becoming scarce which had increased public awareness towards this issue and hence inevitable arisen the uses of renewable resources (Faruk *et al.*, 2012). Natural fiber reinforced composites (NFRC) as a replacement for polymer-matrix composite, such as glass of carbon fiber reinforced plastics (GFRP/CFRP) have received considerable attention from public recently. In addition, it is reported that a target was set by US Department of Agriculture (USDA) and the US Department of Energy (DOE) which is the implementation of 10% of basic chemical building blocks replace with renewable resources by 2020 and aimed to increase to 50% by 2050 (Gurunathan, Mohanty and Nayak, 2015). Natural fibers are biodegradable, recyclable and economical in the manufacturing process compared to synthetic fibers. Moreover, natural fibers are low density and high mechanical strength which are better than the traditional reinforcements. Bamboo fiber also known as “natural glass fiber” is capable to be the reinforced fibers in polymeric composite material because of the high specific strength and stiffness which are comparable with glass fibers (Zakikhani *et al.*, 2014).

1.3 Research Objectives

The purpose of this study is to determine the potential use of *Beting* bamboo fiber reinforced composite plate (BFRCP) in external strengthening of reinforced concrete beam. The following are the objectives set in this study:

1. To determine the mechanical properties of *Beting* species of bamboo.
2. To determine the mechanical properties *Beting* bamboo fiber composite plate as external strengthening material.
3. To evaluate the structural behaviour of RC beams strengthened in flexure using bamboo fiber composite plate.

1.4 Scope of Study

The bamboo used in this research is Malaysian bamboo, which obtained from Raub, Pahang. The bamboo species that used in this study is *Gigantochloa Levis*, also known as *Buluh Beting* of age range from 3 to 4 years old which provide high strength feature.

The preferred concentration of alkaline solution for bamboo culm treatment as alkali-retting was 10% of sodium hydroxide (NaOH) for about 48 hours. From the previous study, the result shown that at fiber content of 40% per volume, the tensile strength is the maximum compared to fiber volume ratio of 0%, 10%, 20% and 30% (Tong, 2017). Hence, the ideal volume ratio of bamboo fiber with 40% is chosen to make bamboo fiber – epoxy reinforced composite plate (BFRCP) which then to be used in strengthening of RC beams.

The reinforced concrete (RC) beams used in this study were in the same dimension, which is a width of 100 mm, a depth of 130 mm and a length of 1600 mm. Pre-mixed concrete with targeted 30 MPa compressive strength at day 28 were used. Main bar with a diameter of 10 mm and 6 mm shear link were mainly utilized as the reinforcement in all the beams in this experiment. There are eight RC solid beams were cast, which includes three controlled beams, three beams without shear reinforcement in flexure zone un-strengthened with BFRCP and two beams without shear reinforcement in flexure zone strengthened with BFRCP in the mid-span zone. The purpose of removing shear links in the flexure zone is to promote flexural failure as well as to evaluate the effective strengthening of the BFRCP plate in flexure.

In four-point loading test, a simply-supported method was applied at the bottom of the beam from the end of both sides with 100 mm. Meanwhile, two loading points were added to the top of the beam by 200 mm apart from each point. The load-deflection behaviour, crack patterns and failure mode of the beams were observed and discussed in the following chapter.

1.5 Research Significance

Nowadays, green technology in the field of material science has become more popular through the development of bio-composite in order to overcome the environment and sustainability issues. Replacement of synthetic fiber with natural fiber is becoming more popular in the manufacturing of composite in worldwide. This is because the production of synthetic fibers consumed very high energy and bring the negative impact to human health and the environment. Hence, the study intends to investigate the potential of replacement of synthetic fiber composite plate with bamboo fiber composite plate as a structural engineering solution to increase the bending behaviour of reinforced concrete beams. Mechanical behaviour of the bamboo and bamboo fiber reinforced composite plate are identified in this study. This research also aimed to know the structural properties of RC beam as well as the effective strengthening of BFRCP of RC beam in flexure in terms of load-deflection, crack patterns and failure mode tends to prove the effectiveness use of BFRCP in strengthening purposes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the overview and literature review of past researches on the effects of external strengthening material of reinforced concrete (RC) beams are elaborated. Discussion on a few types of natural fibers and the methods to enhance the performance of bio-composites are presented. Besides, the structural behaviours of the external strengthening of RC beam using natural fiber reinforced polymer composite (NFRPC) are presented and discussed.

2.2 Natural Fiber

Fibers are classified into natural fibers and synthetic fibers. Natural fibers may be obtained from plant, animal, and mineral sources. The example of animal fibers included wool and silk, whereas, for mineral fiber including asbestos. For plant, or cellulose-base fibers were categorized according to their application which included primary and secondary plants. Figure 2.1 summarizes the classification of natural fibers and synthetic fibers by groups.

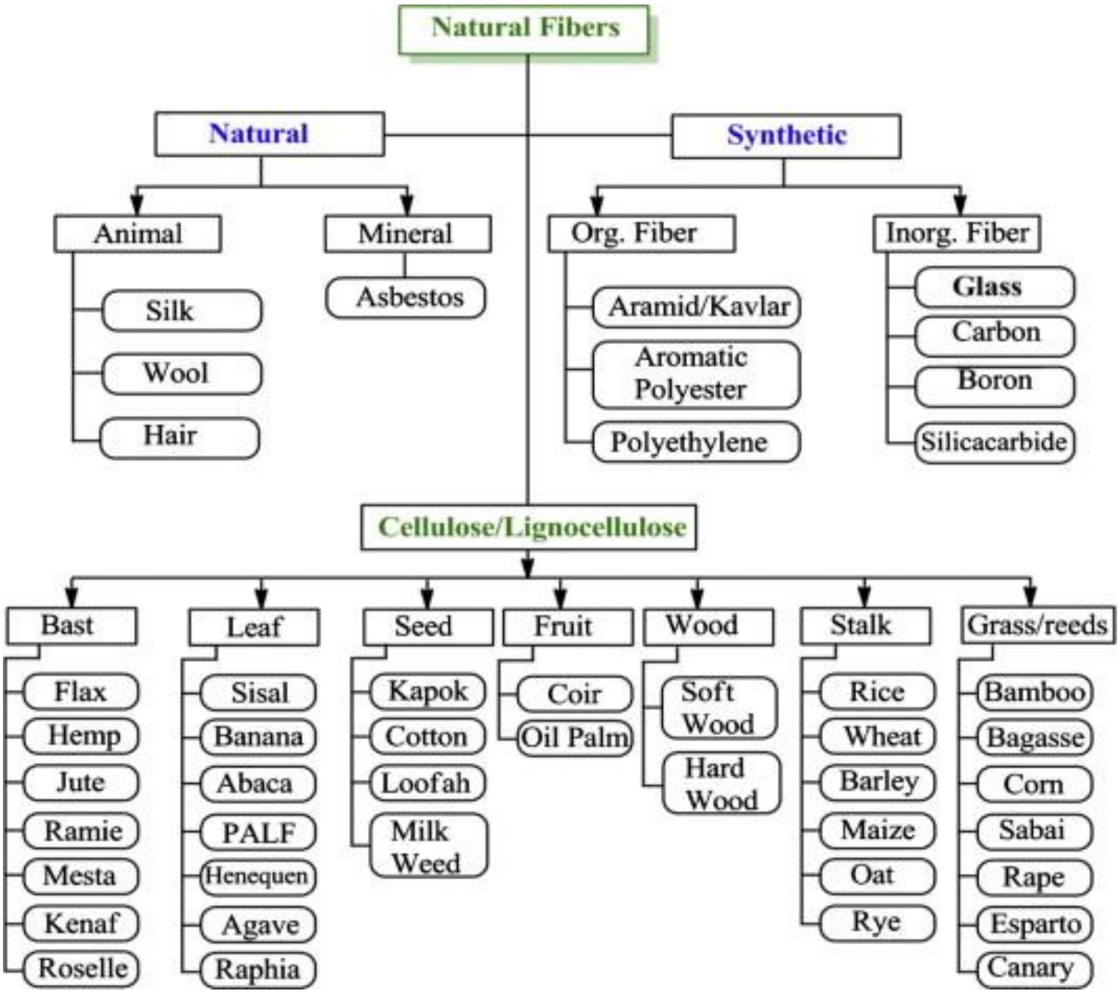


Figure 2.1 Classification of natural and synthetic fiber.

Source: Gurunathan *et al*. (2015)

There are three primary chemical compositions presences in lignocellulosic fibers such as cellulose, hemicelluloses and lignin. Besides, lignocellulosic fibers consist of small amounts of waxes, pectin and water-soluble substances. The natural fibers cell structures are relatively complicated, which are made up from a composite of rigid cellulose microfibrils embedded in a soft hemicellulose and lignin matrix. Figure 2.2 shows the structural constitution and arrangement of a natural vegetable fiber cell. The physical properties of the fibers can be identified by the basic elements such as cellulose, hemicellulose and lignin. Despite that, the amount of these elements varies from plant due to age, species and various parts of the same plant. Cellulose is the most important component in plant-fibers since it contributes the mechanical properties due to the stiffest and strongest properties. This is proven in Table 2.1 and Table 2.2 that pineapple fiber with higher cellulose content gives better mechanical properties.

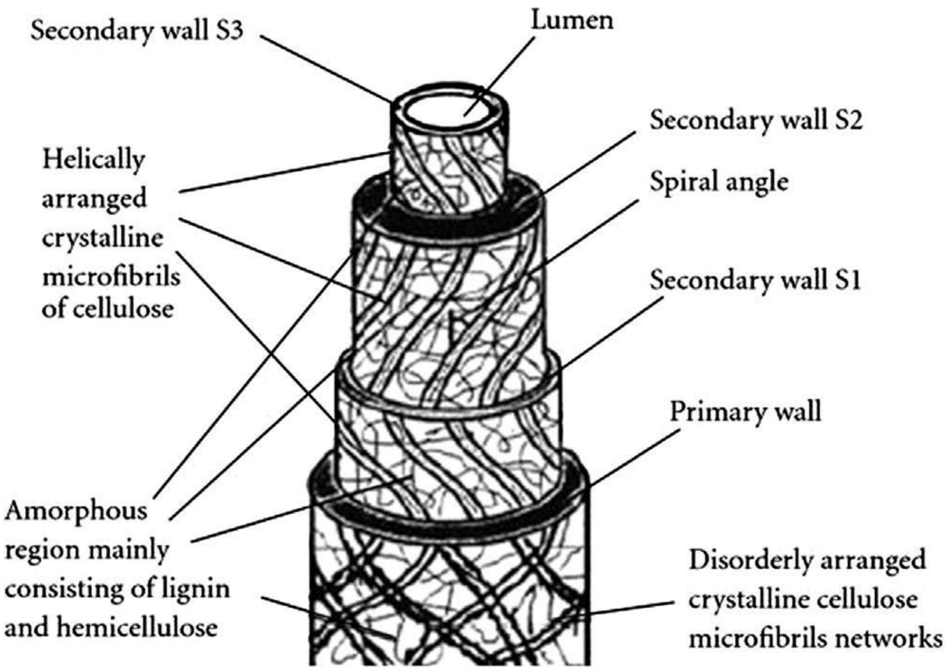


Figure 2.2 Structural constitution and arrangement of a natural vegetable fiber cell.

Source: Dicker *et al.* (2014)

Table 2.1 Chemical composition of some natural fibers.

Fiber	Cellulose (wt%)	Lignin (wt%)	Hemicellulose (wt%)	Wax (wt%)
Bast				
Flax	71.0	2.2	18.6-20.6	1.7
Hemp	70.2-74.4	3.7-5.7	17.9-22.4	0.8
Jute	61.0-71.5	12.0-13.0	13.6-20.4	0.5
Kenaf	31.0-39.0	15.0-19.0	21.5	-
Ramie	68.6-76.2	0.6-0.7	13.1-16.7	0.3
Leaf				
Abaca	56.0-63.0	7.0-9.0	20.0-25.0	3.0
Curaua	73.6	7.5	9.9	-
Henequen	77.6	13.1	4.0-8.0	-
Pineapple	70.0-82.0	5.0-12.0	-	-
Sisal	67.0-78.0	8.0-11.0	10.0-14.2	2.0
Seed/Fruit				
Coir	36.2-43.0	41.0-45.0	0.15-0.25	-
Cotton	82.7	-	5.7	0.6
Oil Palm	65.0	-	29.0	-
Grass				
Bagasse	55.2	25.3	16.8	-
Bamboo	26.0-43.0	21.0-31.0	30.0	-
Straw				
Rice	41.0-57.0	8.0-19.0	33.0	8.0-38.0
Wheat	39.0-45.0	13.0-20.0	15.0-31.0	-
Others				
Rice Husk	35.0-45.0	20.0	19.0-25.0	14.0-17.0

Source: Ramamoorthy *et al.* (2015)

Table 2.2 Mechanical properties of some natural and man-made fibers.

Fiber	Density (g/cm^3)	Tensile Strength (MPa)	E-Modulus (GPa)	Elongation at break (%)
Bast				
Flax	1.5	345-1100	27.6	2.7-3.2
Hemp	-	690	30.0-60.0	1.6
Jute	1.3-1.4	393-773	13.0-26.5	1.2-1.5
Kenaf	-	930	53.0	1.6
Ramie	1.5	400-938	61.4-128.0	1.2-3.8
Leaf				
Abaca	1.5	400	12.0	3.0-10.0
Curaua	1.4	500-1150	11.8	3.7-4.3
Pineapple	-	413-1627	34.5-82.5	1.6
Sisal	1.4	468-640	9.4-22.0	3.0-7.0
Seed/Fruit				
Coir	1.1	131-175	4.0-6.0	15.0-40
Cotton	1.5-1.6	287-800	5.5-12.6	7.0-8.0
Oil Palm	0.7-1.55	248	3.2	25.0
Grass				
Bagasse	1.25	290	17	-
Bamboo	0.6-1.1	140-230	11-17	-
Man-made				
Aramid	1.4	3000-3150	63.0-67.0	3.3-3.7
Carbon	1.7	4000	230-240	1.4-1.8
E-glass	2.5	2000-3500	73.0	2.5
S-glass	2.5	4570	86.0	2.8

Source: Ramamoorthy *et al.* (2015)

Natural fibers have increased the attention of researchers for application in housing, consumer good and civil structures. There are many advantages of using natural fibers instead of using synthetic fibers like low density, light weight, low cost, non-toxicity, acceptable specific properties, renewable and biodegradable.

2.3 Bamboo Fiber

Bamboo (botanical name: *Bambusa*) is one of the fastest growing grassplants among the natural fibrous plants and it is richly found in many countries especially in Asian country (Ramamoorthy, Skrifvars and Persson, 2015). Bamboo belongs to the grass family *Bambusoideae*. It is well known as the rapid growing woody plant in the world due to its unique rhizome-dependent system. It can grow up 96 cm within a 24-hour period and reached its maximum height within 3 months. Hence, the bamboo can reach the maturity in 3-4 years prior to harvest and utilize. The bamboo plant is classified as a versatile and sustainable resource since the fast growth rate and ability to live in diverse climates.

Bamboo is a natural ligno-cellulosic composite, in which consists of cellulose fiber embedded in a lignin matrix (Zakikhani *et al.*, 2014). The chemical constituent of bamboo fiber is hemicellulose (30%), cellulose (26–43%) and lignin (21–31%) which shown in Table 2.1. Bamboo fibers have a considerable high percentage of lignin compared with other natural fibers, resulting in its high strength. The bamboo fibers are aligned longitudinally and unidirectional with nodes along its length. Due to these properties, bamboo culm is considered a special structure and useful in transferring of load. As bamboo fiber is aligned in such pattern help it to improve the strength with respect to its weight which then often called as 'natural glass fiber' (Okubo, Fujii and Yamamoto, 2004).

The relatively high ultimate tensile strength of bamboo fiber which able to reach 440 MPa to 600 MPa as shown in Table 2.3. The enchanting properties of the bamboo fiber contributes to become as an attractive alternative to steel in tensile loading application (Ku *et al.*, 2011).

Table 2.3 Comparison of tensile properties of natural fibers.

Fiber name	**Density (kg/m^3)**	**Diameter (μm)**	**Tensile strength (MPa)**	**Tensile modulus (GPa)**	**% Elongation at break**
Sisal	1450	80-300	227-700	9-20	3-14
Coir	1150	100-460	131-175	2.5-6	15-40
Banana	1350	80-250	529-759	8-20	1-3.5
Bamboo	910	88-330	440-600	35-46	14
Jowar	922	80-500	302	6.99	4.32

Source: Ratna Prasad & Mohana Rao (2011)

Material's behaviour when subjected to loads was determined by mechanical analysis. The fiber aspect ratio, fiber orientation and fiber-matrix are the main aspects affect the mechanical properties of the cellulose. Several studies have been conducted on bamboo fiber reinforced composites and concluded that the mechanical properties of bamboo deviate with different testing methods adopted and different samples tested (Rassiah and Ahmad, 2013).

A study on investigation of microfibrils extracted from raw bamboo was carried out by Krishnaprasad et. al., (2009). Polyhydroxybutyrate (PHB) and bamboo microfibril composite were prepared with different fiber loading. Based on the research, the higher the bamboo microfibril loading in the composite, the stronger the tensile strength and impact strength. However, the tensile and impact strength of composite showed a decrease in strength after reached an optimum microfibril loading.

Table 2.4 Mechanical properties of PHB and composites with bamboo microfibrils.

Sample	Tensile strength (MPa)	Young modulus (MPa)	Elongation at break (%)	Impact strength (kg/m^2)
PHB pure	10.99	1044	1.94	595
PHB5	9.73	1256	2.28	953
PHB 10	11.05	1388	2.25	991
PHB 20	12.05	1824	1.70	748
PHB 30	11.17	2165	0.96	510

Source: Krishnaprased *et. al.* (2009).

2.3.1 Malaysia bamboo

Malaysia is furnished with over 50 species of bamboo, 25 of them are indigenous and the remaining are exotic. The bamboo species are typically from seven genera of *Dinochloa, Bambusa, Dendrocalamus, Racemobamboos, Schizostachyum, Thyrsostachys* and *Gigantochloa*. However, only a little of them harvested commonly for commercialization, including *Gigantochloa Levis, Gigantochloa Ligulata, Gigantochloa Scortechinii Gamble (G. scortechinii), Gigantochloa Wrayi, Schizostachyum Brachycladum, Schizostachyum Grande* and *Schizostachyum Zollingeri* (Nordahlia *et al.*, 2012)

2.3.1.1 Gigantochloa levis

Gigantochloa levis also known as *Buluh Beting* is an evergreen clump-forming bamboo that can grow 15 to 20 metres tall. The bamboo is a rapid growth plant which the number of culms increased from 3.6 to 4.3 after 3 years planting and continuously increased to 9.4 after 5 years of planting. *Beting* bamboo is often cultivated in parts of southeast Asia, and is known as a good quality edible shoots, long, straight canes bamboo. Production and trade of edible shoots and strong culm is locally important. *Beting* bamboo grows reasonably well on a large range of sites, except where the soil is too sandy or too dry. The culms of bamboo are straight and long which can be harvested when about a year old for making handicrafts while for bamboo at least three years can be taken for construction purposes such as construction of framework. Besides, this bamboo also used in the fishing industry which can be used for making rafts, fish traps etc. In the Philippines, modern furniture is crafted from the culms.

2.4 Fiber Surface Treatment

Many studies about surface modification on fiber have been carried out and concluded the modification contribute to the enhancement of the performance of natural fibers. High cellulose contains in plant fibers consist of a huge number of hydroxyl group which provide hydrophilic properties that caused the fibers to attract high amounts of water. The poor interaction between fiber and matrix is shown when hydrophilic fibers reinforce hydrophobic matrixes. Hence, the natural fibers need to be processed to improve the compatibility between fiber and matrix by taking out the impurities and reducing the fiber hydrophilicity (Alvarez *et al*., 2003; Cruz & Fangueiro, 2016). Surface modification was divided into physical and chemical methods.

Figure 2.3 illustrates the chemical methods available to treat natural fibers (Gurunathan, Mohanty and Nayak, 2015). The activation of hydroxyl groups in fiber and introduction of new groups that can help the interaction with the matrix can be done by chemical modification method. Such modifications not just improve their usability with the polymer matrices, but also cut the moisture absorption, sometimes impart special properties and ease of processing.

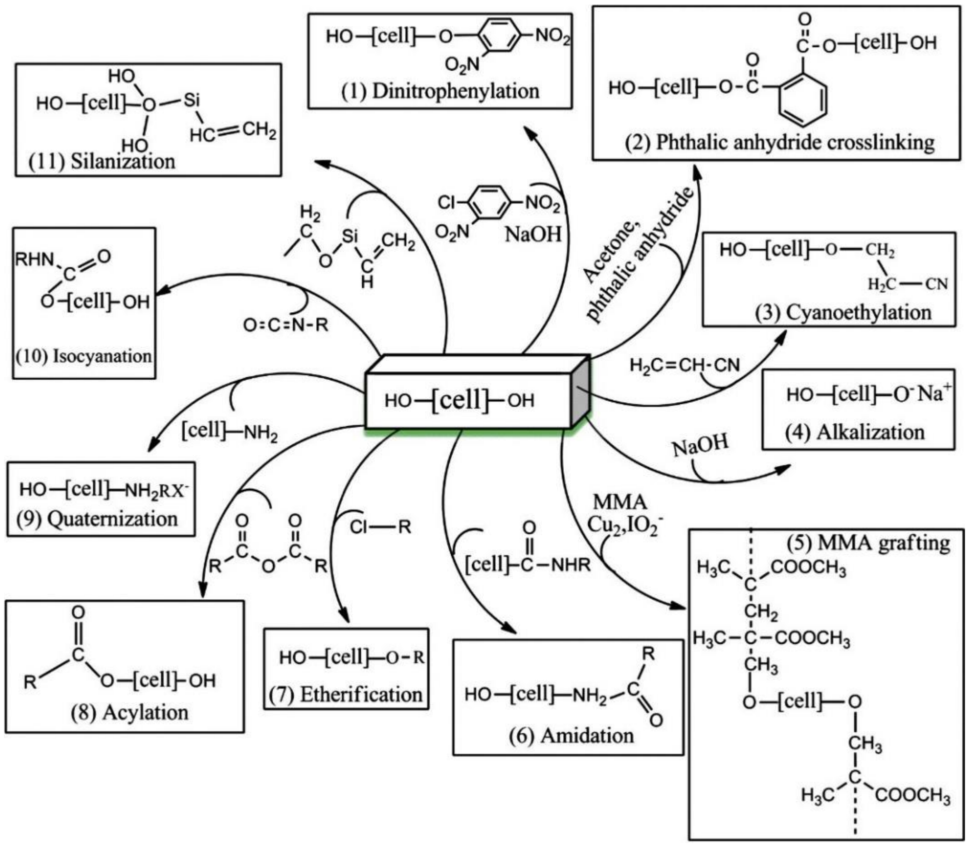


Figure 2.3 Schematic presentations of surface modifications of natural fiber.
Source: Gurunathan *et al*. (2015)

2.4.1 Alkaline Treatment

Alkaline treatment also known as alkalinisation is a popular chemical modification method to remove impurities such as lignin, wax and oils that covered on the surface of fiber cell wall. Overall the reaction can be represented as Equation 2.1.

$$Fiber\text{-}cell\text{-}OH + NaOH \rightarrow Fiber\text{-}cell\text{-}O\text{-}Na^{+} + H_2O + Impurities \qquad 2.1$$

Alkaline treatment is important when fiber used to reinforce in thermoset or thermoplastics. Fiber surface modification is essential to break the hydrogen bonds in the network structure and hence roughen the fiber surface. The -OH groups present in the cellulose molecules are alkali sensitive. These groups react with the water molecules and act out of the fiber. The remaining reactive OH^- groups convert to ONa^- groups and thus the hydrophilic hydroxyl group is reduced. This reduces the moisture uptake tendency of the fiber (Kuila and Sharma, 2017). The surface tension, hence wetting ability, of mercerized fibers is higher, resulting into improved bonding through mechanical interlock between the matrix and the roughened surface.

The relationship between alkali treatment on the wetting ability and coherence of sisal–epoxy composites had been examined (Bisanda, 2000). Established on the research, the adhesion properties were enhanced after the alkali treatment due to the increased in surface roughness and surface tension. By get rid of the waxy surface stances and lignin, it enhanced the possibility for mechanical interlinking and chemical bonding. The resulting composites showed gained in the compressive strength and water resistance. Figure 2.4 shows the compressive strength of sisal-epoxy composites with alkaline treated and untreated fibers.

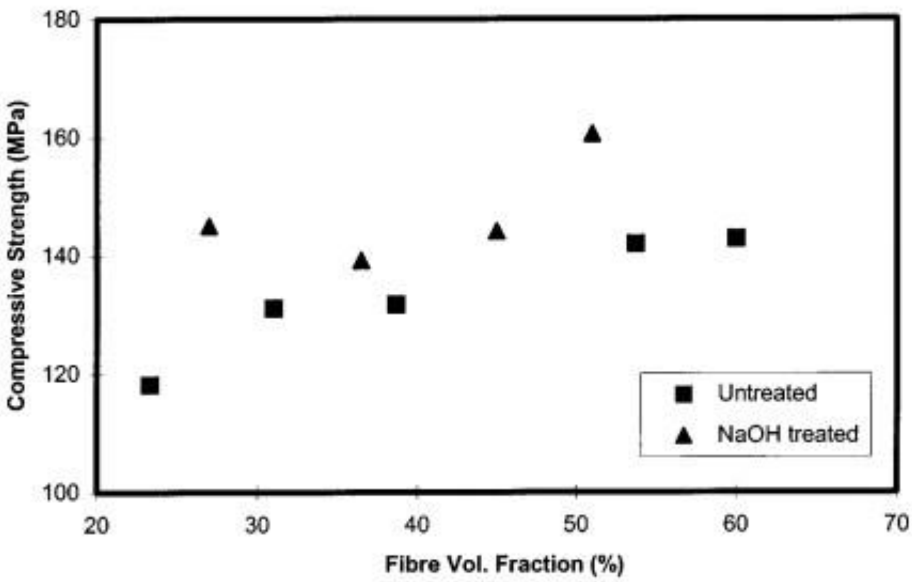


Figure 2.4 Compressive strength of sisal-epoxy composites.
Source: Bisanda (2000)

The tensile properties of ramie fibers after alkylation was explored and shown in Table 2.5. The condition (I) indicates the ramie fibers without treatment and condition (II) indicated ramie fibers with alkali treatment. 15% concentration of NaOH was used to treat the ramie fiber and was subjected to applied loads of 0.049 and 0.098 N. The outcome indicated that the tensile strength of the mercerized ramie fiber was increased about 18% more than for un-mercerized ramie fibers. Besides, it showed that treated fibers with load application increased significantly in fracture strain, twice to three times higher than that of untreated fiber (Goda *et al.*, 2006).

Table 2.5 Tensile properties of load applying alkali-treated ramie fiber.

Applied load (N)	**Fiber diameter (mm)**	**Fracture load (N)**	**Tensile strength (MPa)**	**Fracture strain (%)**
		Condition (I)		
0	0.049	0.252	151	0.045
0.049	0.046	0.434	306	0.061
0.098	0.044	0.562	441	0.065
		Condition (II)		
0	0.031	0.380	550	0.069
0.049	0.028	0.408	661	0.072
0.098	0.026	0.373	606	0.072

Source: Goda *et al*. (2006)

2.5 Thermoset and Thermoplastic

Matrix is the most important component that used in the fabrication of FRP which function as an adhesive to bind the fibers together. Other than that, matrix also function as the protection layer for fibers from environmental attack and degradation. There are two major types of matrix which are thermosetting matrix and thermoplastic matrix. Matrix also functioned to chemically and thermally compatible with the fibers.

Thermosetting matrices are the polymers that cross-linked together to form long-chain molecules by primary chemical bonding. Therefore, thermosets are irreversible at increased temperature. Moreover, thermosetting matrix has good chemical resistance and low stress relaxation properties compared to thermoplastic matrix. These properties were the main factors that contributed the application of thermosetting matric in the structural engineering. There are three main types of thermosetting matrix including vinylester resin, polyester resin and epoxy resin (Chandra Das and Haque Nizam, 2014).

Thermoplastic matrices are formed by relatively weak Van der Waals forces long-chain molecules, still, have strong bonds within particular molecules. Hence, the molecules can move freely at increased temperature without altering the molecular structure. Thermoplastic included polypropylene and nylon.

2.5.1 Epoxy Resin

Hand lay-up application of FRP composites is usually choosing epoxies as the resin due to the ability to completely cure at room temperature and the magnificent adhesion properties. There are many benefits of epoxy which are high strength, good dimensional stability and chemical resistance. These advantages help extensively used for industrial purposes such as aerospace and automotive structures, coatings, electronic components and adhesives. However, the price of epoxy was much more higher than other type of resin such as polyesters and vinyl esters (Chandra Das and Haque Nizam, 2014). From the graph, it was clearly proved that epoxy had a higher yield strength and higher load capacity as compared to polyester and vinylester before failure. Epoxy resin also able to sustain a higher deformability and experience failure after reaching an ultimate load.

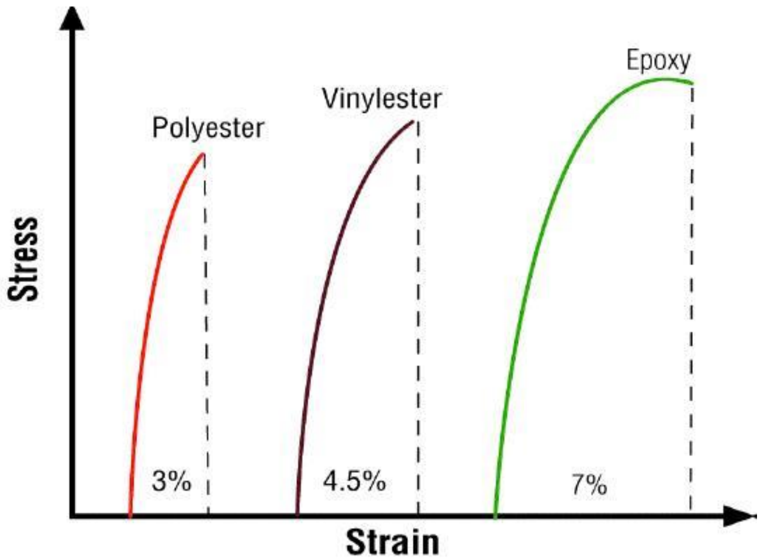


Figure 2.5 Comparison of stress-strain curve of polyester, vinylester and epoxy.
Source: Mahjoub *et al*. (2013)

2.6 Natural Fiber Reinforced Composite (NFRC)

Natural fiber reinforced composite (NFRC), also known as bio-composite was proposed to take over the synthetic fiber reinforced composite. Nowadays, replacement of synthetic fibers with natural fibers is getting more popular, since it can help to improve economic, environmental and social benefits. This kind of research had attracted the attention and interest of engineers and researchers as natural fiber composites have the potential to be an alternative ways to the ever-depleting non-renewable resources (Dhakal *et al.*, 2015). NFRC provides a wide range of advantages including high strength to weight ratio, low density, high toughness, easier to fabricate for complex shapes in manufacturing process, lower energy consuming from processing fiber to completion of composite (Sen and Reddy, 2014). Figure 2.6 shows the energy for production of natural fibers are much lower than the consumption by synthetic fibers.

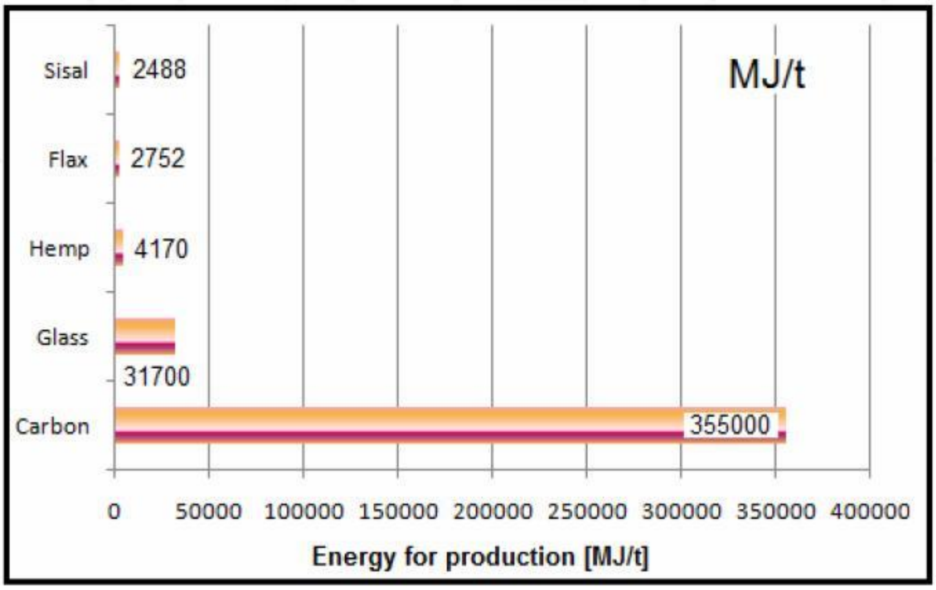


Figure 2.6 Energy for production of some fibers (MJ/T).
Source: Jauhari *et al*. (2015)

The properties of natural fiber composite are different to each other according to previous studies, because of different kinds of fibers, sources and moisture conditions. The performance of NFRCs relies on some factors such as mechanical composition, microfibrillar angle, structure, defects properties, chemical properties and also the adhesion between fiber and the matrix (Mohammed *et al.*, 2015).

Ramesh *et al*. (2013) has conducted a research about sisal-jute-glass fiber reinforced polyester composites and comparison of mechanical properties between sisal-glass fiber and jute-glass fiber reinforced polyester composites. It was clearly being seen that the sisal-jute-glass fiber improved the properties and used as an alternative for glass fiber reinforced composite. Figure 2.7 shows the graph of load versus displacement for the mentioned composites. From the result, the displacement was directly proportional to the load and cracks appeared when reached a 14.2 mm displacement. According to the interfacial properties, the internal cracks of the composites had proven that the sisal-jute-glass fiber reinforced composites performed better than the rest of the tested composites.

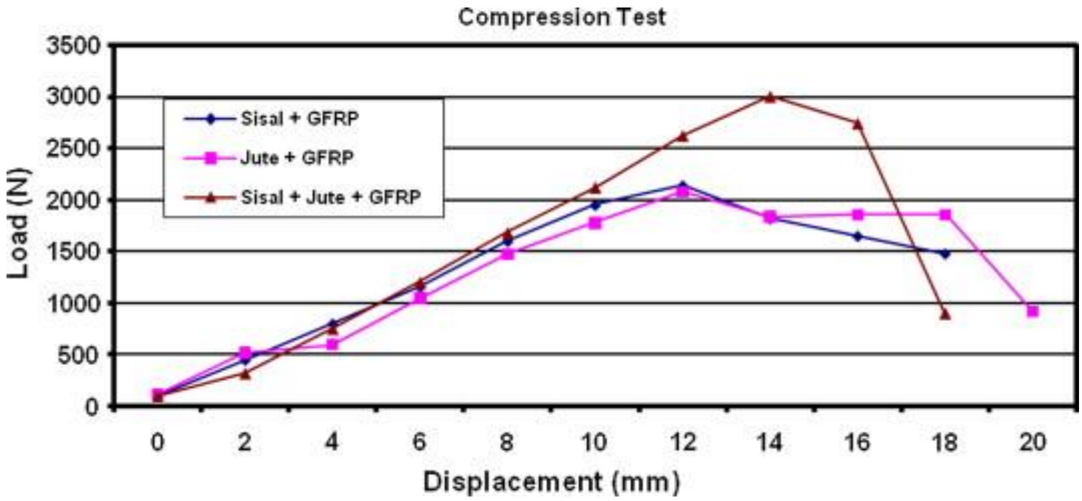


Figure 2.7 Comparison of load vs. displacement of sisal-glass fiber, jute-glass fiber, and sisal-jute-glass fiber reinforced composites.

Source: Ramesh *et al*. (2013)

2.7 Fiber Volume Ratio

Fiber volume ratio defined the weight of fiber loading in a specified volume. The increase in fiber loading in a fixed volume indicated that the decrease in the weight of matrix resin. For instance, when a composite plate filled with 30% fiber loading, the remaining 70% filled with matrix resin. The fiber loading ratio will affect the mechanical behaviour of the composite plate. In general, the increase in the fiber volume ratio, the higher the stiffness properties of the composite plate.

Tensile properties for sisal, jowar and bamboo fiber reinforced composite showed an increase in strength with the increase in the fiber volume ratio as shown in Figure 2.8. The tensile strength of jowar fiber reinforced composite was almost the same with the bamboo fiber reinforced composite. Besides, there was recorded that the tensile strength of jowar composite was 1.89 times higher than the sisal composite plate at 40% fiber loading. This increment was associated with the high strength of jowar fiber compared to that of sisal and stronger adhesion with the polyester matrix.

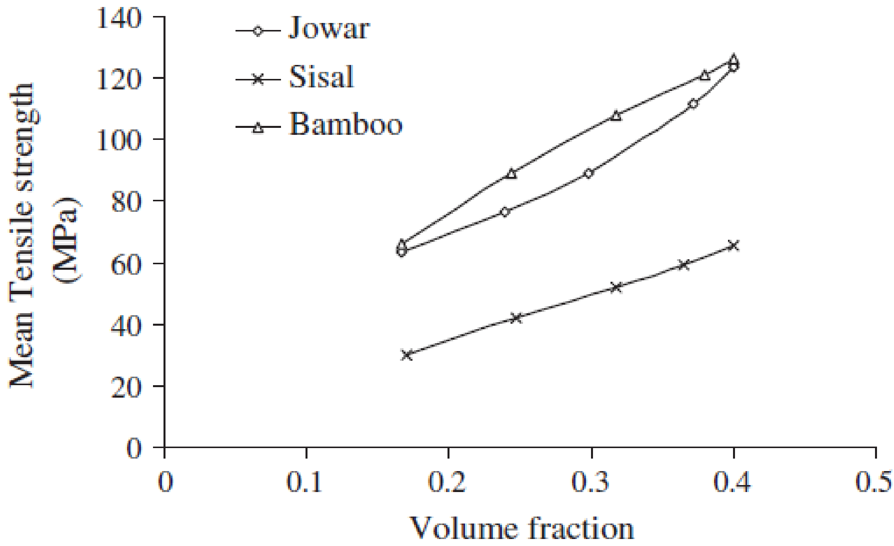


Figure 2.8 Effect of volume fraction of fiber on mean tensile strength of various natural fiber composites.

Source: Ratna Prasad & Mohana Rao (2011)

2.8 Mechanical Properties

The mechanical analysis is to study the behaviour of the material under applied load. In the research, the samples were fabricated according to American Society for Testing and Materials (ASTM) standard. Two mechanical tests were carried out which included tensile test on fiber plate (ASTM D3039) and flexural test on fiber plate (ASTM D790-03).

2.8.1 Tensile Test on Fiber Plate (ASTM D3039)

Unidirectional kenaf fiber epoxy was studied in terms of tensile test with dimension of 230 mm x 170 mm and thickness of 5 mm. The specimens were subjected with a constant rate of 2 mm per minute up to fracture at 25ºC in accordance to ASTM D3039. The tensile test measured the ultimate tensile strength and Young's modulus of the composite coupon.

Based on the study, the result is listed in Table 2.6. The tensile strength at the break for the neat epoxy composites scored 36.56 MPa. At 0.15 fiber volume ratio, the tensile strength of the composites almost reached 60 MPa. The strength continued to increase up to 100 MPa with a fiber content ratio of 0.45. The figure illustrated an increment of 58% and 175% in terms of ultimate tensile strength at 15% fiber reinforced and 45% fiber reinforced specimens respectively, as compared to the pure epoxy specimen. The corresponding increases in tensile modulus are 34% and 166% respectively.

Table 2.6 Mechanical properties of pure epoxy and its kenaf reinforced composite.

Mechanical properties	Pure	15%	45%
Ultimate tensile strength (MPa)	36.56	57.95	100.56
Young's modulus (GPa)	2.92	3.96	7.78

Source: Abdullah *et al*. (2012)

2.8.2 Flexural Test on Fiber Plate (ASTM D 790-03)

Flexural test represents the flexibility of the materials under static loading. From the previous study, malva fiber reinforced composite plate was prepared with dimension of 122 mm x 25 mm x 100 mm. The matrix used in the study was a diglycidyl ether of the bisphenol A (DGEBA) epoxy resin mixed with trietylene tetramine (TETA) as hardener. A model 5582 Instron machine with 100 kN of capacity was used for three-point bending test and a strain rate of 1.6×10^{-2} s^{-1}, followed the ASTM D790-03 standard (Margem *et al.*, 2015).

Figure 2.9 shows the flexural strength of the composite plate with different fiber volume ratio. The fibers were aligned longitudinal and continuously in the process of fabrication. From the figure, the significance increased in the flexural strength indicated the incorporation of malva fibers and the epoxy matrix. Thereby, a straight-line graph was obtained from the result collected. The results gained from the experiment were as the expected because the flexural strength of the malva fiber reinforced composite was 214 - 497 MPa which was higher strength compared to the pure epoxy composite which denoted 28 - 90 MPa.

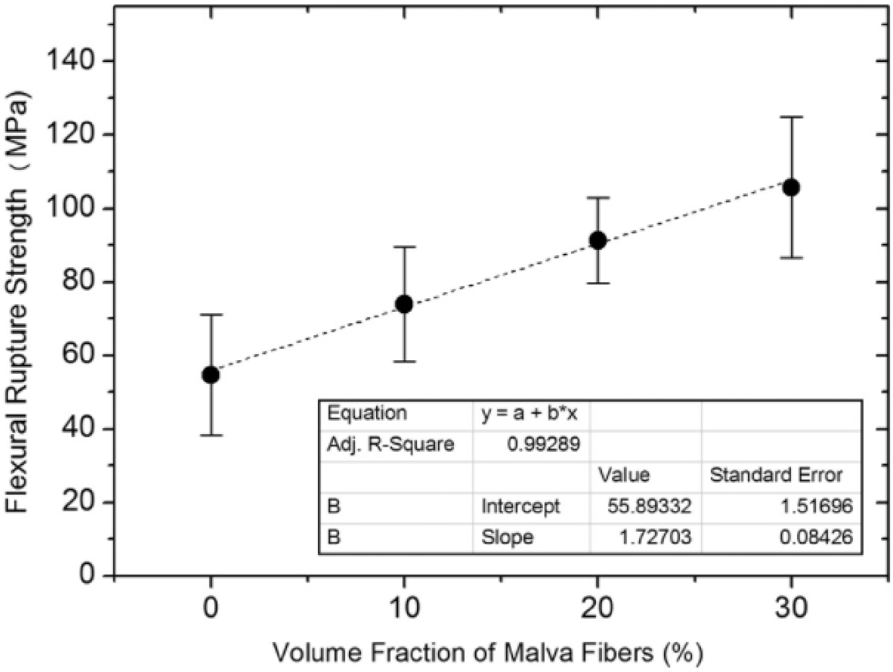


Figure 2.9 Variation of the flexural rupture strength with the volume fraction of malva fibers in epoxy composites.

Source: Margem *et al*. (2015)

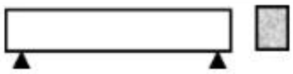
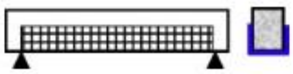
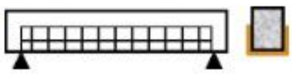
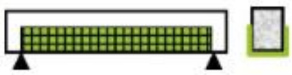
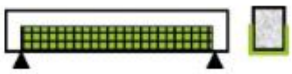
2.9 RC Beam Strengthening Externally Using FRP

Reinforced Concrete (RC) is an extremely popular construction material used for structural components of a building like beams, columns and slabs etc. One major flaw of RC is its susceptibility to environmental attack. This can severely decrease the strength and life of the structures. Maintenance of the structurally deteriorated RC structures become necessary since the structural element ceases to provide satisfactory strength and serviceability. For external strengthening of beam, there are two schemes that commonly applied, including flexural strengthening and shear strengthening to provide strength enhancement and increase the serviceable life. FRP plates or sheets were the common materials for the flexural strengthening of a beam. The FRP sheets were applied onto the tension face of the beam, also known as the bottom face of the beam. The strength of the fiber reinforced polymer was mainly influence by the types of fiber used, the number of layers of FRP and the strengthening techniques adopted. In this section, uses of synthetic and natural fibers in composite application in the past research are presented.

2.9.1 Synthetic fiber

A study on carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP) was carried out by Attari *et al*. (2012). The experiments were conducted by using CFRP, GFRP and hybrid of the two fibers (HFRP). Different number layers of plastic sheets were used to wrap the RC beams for strengthening purpose. The strengthening techniques are shown in Table 2.7. Based on the result obtained in Figure 2.10 and Figure 2.11, the twin layer of CFRP and GFRP had the highest load capacity among all the schemes. The U-anchorage strengthening configuration enhanced the flexural strength and devoted to the redirection of the internal forces. This type of configuration showed the best results.

Table 2.7 Tested beams strengthening schemes.

Beam No.		Strengthening schemes	Type of strengthening	FRP area m^2
	PC		Control specimen	–
Serial A	PA1		CFRP Wrap 1 Layers 0° and 1 layer 90°U Shape	0.78 CFRP
	PA2		GFRP Wrap 2 Layers at 0° and 1 layer 90°U Shape	1.17 GFRP
	PA3		01 Layer GFRP 0° 01 Layer CFRP 0° U Shape	0.39 CFRP 0.39 GFRP
Serial B	PB4		3 Layers HFRP U Shape	1.17 HFRP
	PB5		2 Layers HFRP U Shape	0.78 HFRP
	PB6		3 Layers HFRP	0.39 HFRP

Source: Attari *et al*. (2012)

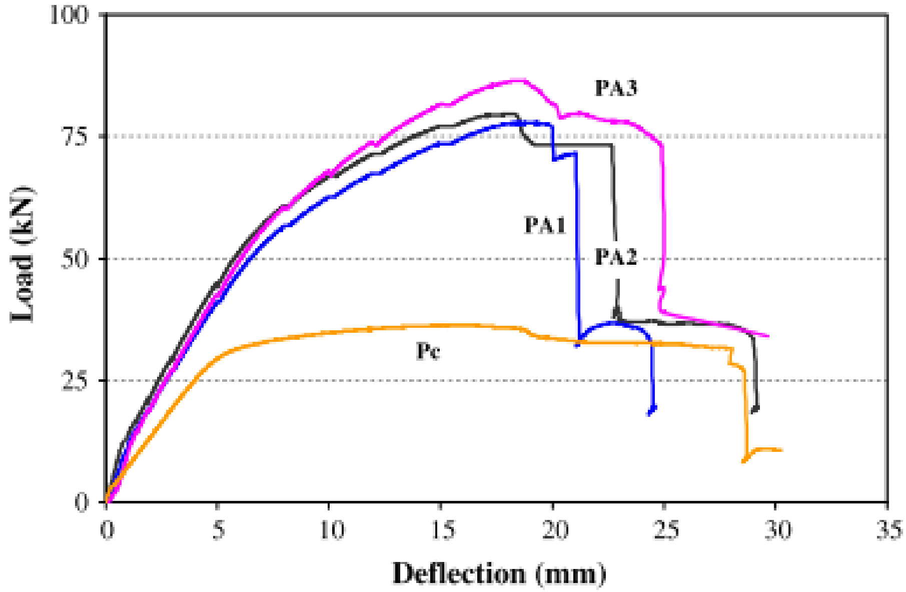


Figure 2.10 Midspan deflection of A serial beams.
Source: Attari *et al*. (2012)

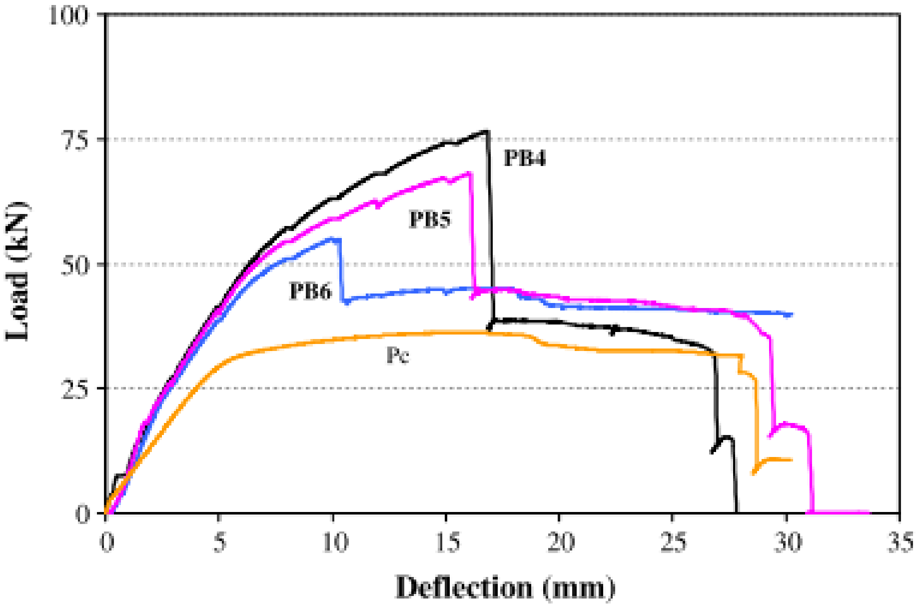


Figure 2.11 Midspan deflection of B serial beams.
Source: Attari *et al*. (2012)

Irshidat *et al*. (2016) investigated the application of carbon nanotubes (CNTs) affect the properties of epoxy resin. CNT was added into the carbon fiber-epoxy composite to identify the performance of the modified epoxy resin in terms of the strengthening efficiency on RC beam. Sixteen RC beams with cross-section of 100 mm x 150 mm and 1550 mm in length were prepared. The behaviour of the beams was determined by using four-point loading test. Table 2.8 summarizes the test program and specimen designation. The four-point loading tests were carried out according to the instrument details as shown in Figure 2.12.

Table 2.8 Test program and specimen designation.

Designation	No. of specimen	Epoxy type	Using CNT modified epoxy	Using CNT enriched sizing agent	Strengthening technique	Number of layers
Control	2	No	No	No	No	0
B-NE	2	Type 1	No	No	Full retrofitting	1
B-CNT	2	Type 1	Yes	No	Full retrofitting	1
B-S-NE	2	Type 1	No	Yes	Full retrofitting	1
B-S-CNT	2	Type 1	Yes	Yes	Full retrofitting	1
B-M-CNT	2	Type 1	Yes	No	Partially retrofitting	1
B-MT-CNT	2	Type 1	Yes	No	Partially retrofitting	1
B-2L-CNT	2	Type 1	Yes	No	Full retrofitting	2

Source: Irshidat *et al*. (2016)

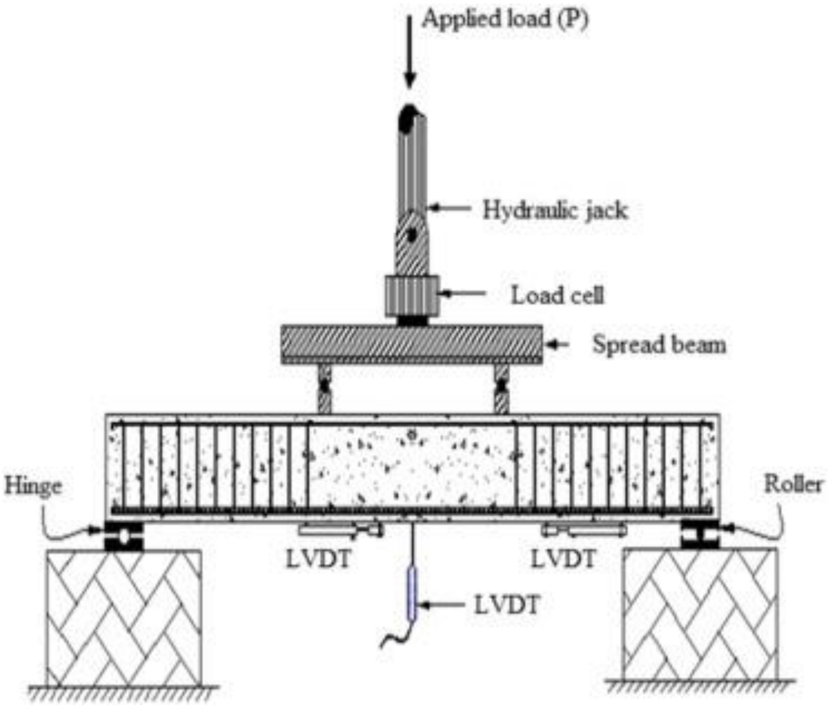


Figure 2.12 Instrumentation details.

Source: Irshidat *et al*. (2016)

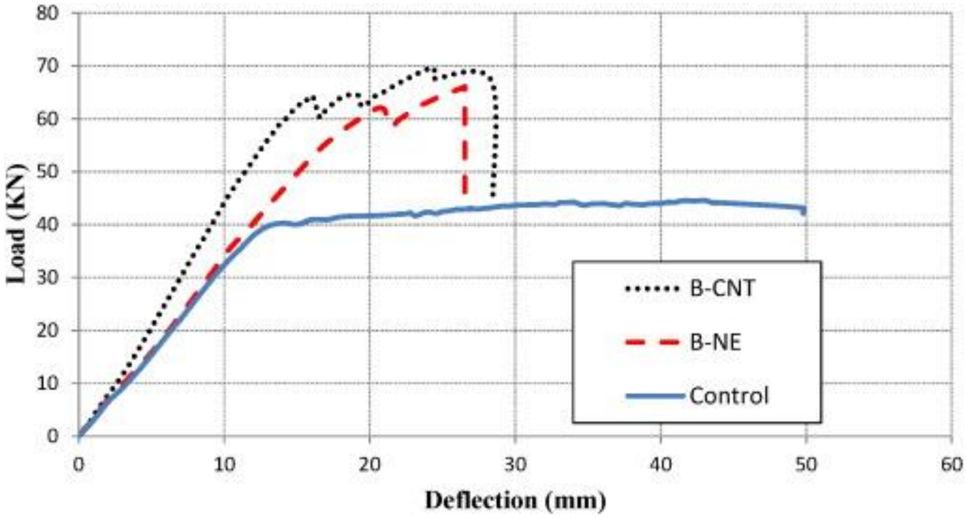


Figure 2.13 Load-deflection response of control, B-NE, and B-CNT specimens.

Source: Irshidat *et al*. (2016)

Table 2.9 Response parameters for tested beams.

Specimen	Ultimate load (kN)	Initial stiffness kN/m	Toughness (kN mm)
Control	44.8	3300	1848
B-NE	66.2	3500	1064
B-CNT	69.7	4720	1364
B-S-NE	60.6	4120	746
B-S-CNT	62.7	3740	1093
B-M-CNT	51.8	3910	395
B-MT-CNT	44.2	3500	585
B-2L-CNT	79.5	4800	935

Source: Irshidat *et al*. (2016)

From Table 2.9 and Figure 2.13, it was reported that the B-CNT specimen, which was the specimen with modifying epoxy resin by using CNTs had an improvement in terms of beam load carrying capacity by 5% than B-NE specimen. In terms of stiffness and toughness, they showed an improvement of 35% and 28% respectively as compared with B-NE specimen. Addition of CNTs in the composite helped to enhance the toughness and hence reduced the microcracks of the composite by improved the energy absorption of the whole system before debonding.

2.9.2 Natural Fiber

Various studies were carried out to identify the mechanical and physical performance of natural fiber reinforced composite in retrofitting RC beam. Kenaf fiber used as the filler in composite plate to externally strengthen at the bottom soffit of RC beams was studied by Khalid and Yatim (2010). RC beams with dimension of 100 mm x 130 mm x 1600 mm were prepared and tested under four-point loading to identify the load-deflection and crack pattern. Kenaf fiber reinforced polymer composite (KFRPC) with size of 100 mm x 1400 mm x 6 mm were fabricated and bonded to the soffit of RC beam by epoxy adhesive. Based on the summary in Table 2.10, the beam strengthened with KFRPC plate had a higher ultimate load as compared with the un-strengthened beam or control beam with an improvement of 41.5%. Therefore, KFRPC plate is capable to resist the tension force of the beam. The load-deflection curves of the beams are presented in Figure 2.14. From the load deflection curve, it was clearly shown that the beam with KFRPC plate had steeper slope compared to the control beam. This indicates that the beam with KFRPC plate is stiffer compared to the control beam.

Table 2.10 Comparison of the ultimate load ratio.

Beam	Ultimate load (kN)	Ultimate load ratio (compared to CB)
Control beam	36.4	1
Beam with KFRPC plate	51.5	1.41

Source: Khalid & Yatim (2011)

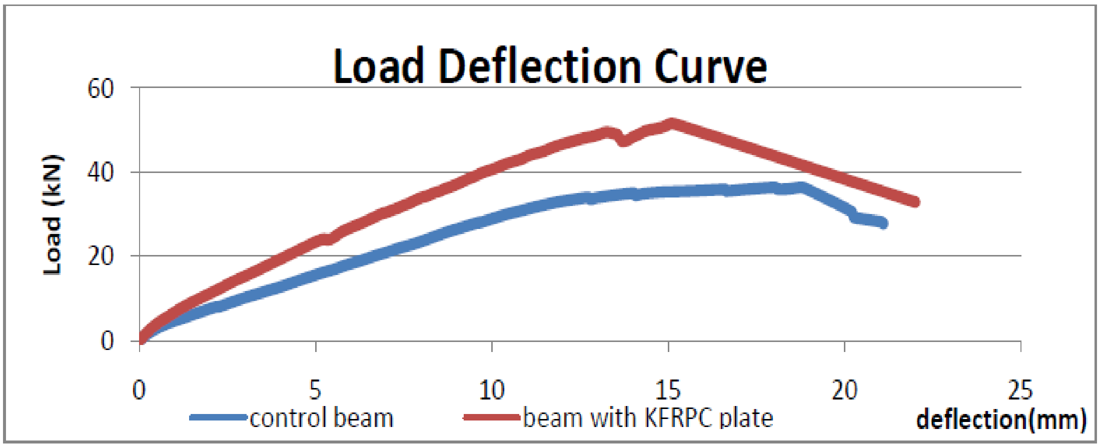


Figure 2.14 Load Deflection Curve of the different beam specimens.

Source: Khalid & Yatim (2011)

2.10 Summary

From the previous researches, it was found that there is still lacking in information about using NFRC in RC beam strengthening even though there is rich in study of mechanical behaviour of NFRC. Although there were numerous extensive theoretical studies and experimental studies has been carried out regarding NFRC such as kenaf fiber in strengthening of RC beam, yet, rarely research about the external strengthening of RC beam using bamboo fiber reinforced composite plate.

Besides, the mechanical properties of raw and dried bamboo were identified in this study since it was rarely found in the previous study. There were two tests, tensile test and compression test carried out. After treated for 24 hours at 103ºC with oven, the dried bamboos were taken out for the mechanical testing. Whereas, raw bamboos were tested without any heat treatment. The mechanical properties of bamboo fiber reinforced composite plates (BFRCPs) were identified according to ASTM D3039 for tensile test and ASTM D790-03 for flexural test.

In this study, the behaviours of the RC beam without shear reinforcement in the flexure zone strengthened externally with BFRCP were identified. The BFRCP was fabricated with dimension of 100 mm x 450 mm x 6 mm (W x L x t) and strengthened at the mid-span soffit of RC beam.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines the procedures for conducting this research which include the preparation and application of bamboo fiber reinforced composite plate (BFRCP), preparation of specimens and laboratory testing. Figure 3.1 shows the flow chart of methodology throughout the research.

3.2 Research Methodology

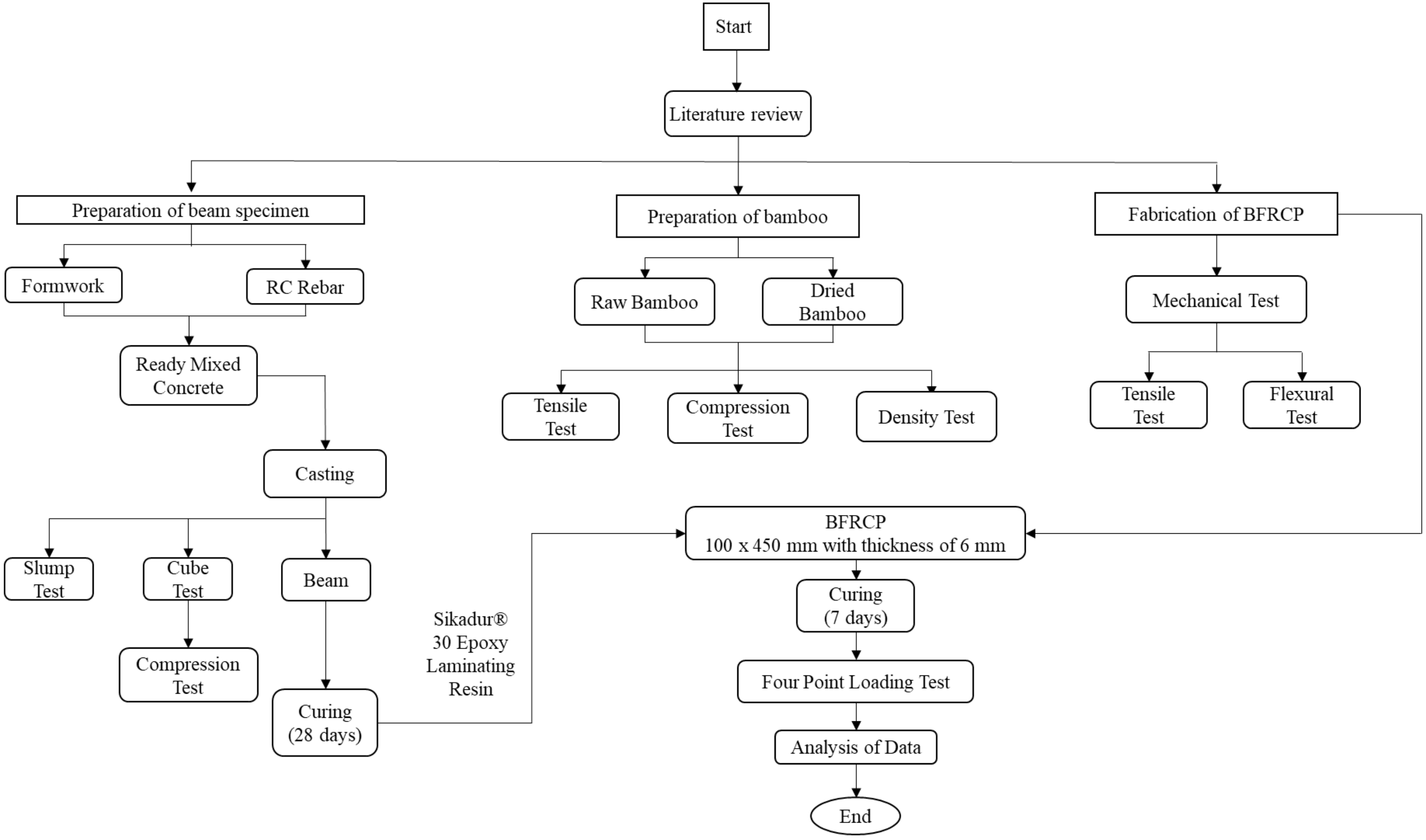


Figure 3.1 Flow Chart of Methodology

3.3 Preparation of Materials

The procedure preparation and function of materials needed in this research are listed in this section.

3.3.1 Extraction of Bamboo Fiber

In this research, bamboo fiber was obtained locally from Raub, Pahang. Lignin plays the role of binding the fibers of cellulose. Alkaline treatment is needed before extraction of bamboo fiber to reduce the lignin content which can ease the cellulosic fiber extraction process (Zakikhani *et al.*, 2014). Sodium hydroxide (NaOH) causes dissolution of lignin by breaking it into smaller segments whose sodium salts are soluble in the medium. Besides, by removing lignin, it can affect the mechanical properties of composite plate (Cruz and Fangueiro, 2016). 10% concentration of NaOH is used to treat the bamboo strips for about 48 hours, then the bamboo strips separated into monofilaments through mechanical process. The nodes parts will be avoided since node will reduce the mechanical properties of composite plate. Hence, fibers were cut into desired length by avoiding the node parts. Then, the bamboo was split into bamboo strips by using a splitter as shown in Figure 3.2 and then the bamboo was passed through a mill-rolling machine to extract the bamboo fibers, as illustrated in Figure 3.3.

Figure 3.2 Bamboo splitting.

Figure 3.3 Mill-rolling process.

After the fibers are extracted, washing of the fibers are carried out by immersing them into water tank to remove the impurities on the fiber surface. Neutralization of bamboo fiber was then carried out by using distilled water to make sure the pH value within the optimum range which is 5-6 pH value. It should be ensured that no thick fibers which can cause voids during fabrication of composite plate. If there is any, separate them manually. Next, the fiber was oven dried with temperature of 60 ºC for 24 hours and then placed into a desiccator and ready to be used. This method of extraction resulted in less fiber damage.

3.3.2 Matrix

Liquid epoxy resin (D.E.R. 331) and modified cycloaliphatic amine hardener (JOINTMINE 905-3S) were chosen as the matrix in the composite plate. The mixing ratio of the epoxy and hardener was 2:1 by volume which referred to the data sheets provided.

Figure 3.4 D.E.R. 331 epoxy resin and JOINTMINE 905-3S hardener.

3.3.3 Sikadur® 30 Epoxy Laminating Resin

Sikadur® 30 in Figure 3.5 was used to provide an efficient structural adhesive bonding between BFRCP with the concrete surface. Sikadur® 30 consist of 2 components: component A (white colour) and component B (black colour) in ratio of 3:1 by volume and density of 1.65g/cm^3. A mixing spindle was used to mix the mixture until uniform light grey colour formed. The pot life of the mixture is 70 minutes. A total of 7 days needed for the mixture to cure before proceeding with the next test to achieve ultimate strength.

Figure 3.5 Sikadur® 30 Epoxy Laminating Resin.

3.4 Fabrication of Bamboo Fiber Reinforced Epoxy Composite Plate (BFRCP)

In this study, the adopted method of fabrication was hand lay-up method and was carried out at room temperature. Stainless steel moulds were used in casting of the BFRECPs. The neat epoxy composite plate and 40% fiber volume reinforced composite plate were fabricated. The 40% fiber volume ratio was chosen since it is the optimum ratio found in previous study (Tong, 2017).

Various sizes of BFRCP were fabricated and tested in each of the experimental testing. For tensile test, the size of plate is 25 mm x 250 mm with a thickness of 5 mm; for flexural test, the size of plate is 12.7 mm x 127 mm with a thickness of 6 mm while the composite plate for external strengthening at bottom soffit of the flexure zone of RC beam were in 100 mm x 450 mm with thickness of 6 mm.

A layer of Teflon paper or fiber cloth was placed on the stainless-steel mould before tightened with screws to avoid adhesion between the composite plate with mould. Consequently, a layer of releasing agent, honeywax was applied on the Teflon paper and surrounding the mould to ease the disassemble process. The bamboo fibers were kept in desiccator before the fabrication of composite. This is to avoid the moisture adsorption of the bamboo fibers and thereby prevent the formation of bubble voids. The bamboo fiber and resin were weighed with specific amount using an electronic balance. The thermosetting matrices were mixed thoroughly using stirring rod. The mixing process was accompanied with gently stirring to minimize the air entrapment.

A thin layer of fluidic epoxy resin was poured into the steel mould and followed by a layer of unidirectional bamboo fibers. The steps were repeated until all the bamboo fibers were filled in the mould with the thickness required. Then, epoxy resin was poured onto the uppermost of the layer to produce a smooth surface of composite plate.

A sheet of fiber cloth was covered on top of the last layer before the pressure was applied to the composite plate to remove the trapped air bubbles inside the plate. Then, the composite plates were placed for 24 hours at room temperature for the curing purpose. During the curing process, the cross-linking bonds were formed among the bamboo fiber and the thermosetting resin. The composite plates were then undergone post-curing process by putting in oven for 4 hours at 110 ºC to ensure the thoroughly cured of thermoset composites. By treated with post-curing process, the composite plates have a more stable and longer lifetime compared to poorly cured (Kumar *et al.*, 2015).

Figure 3.6 Application of mould releasing agent (honey wax).

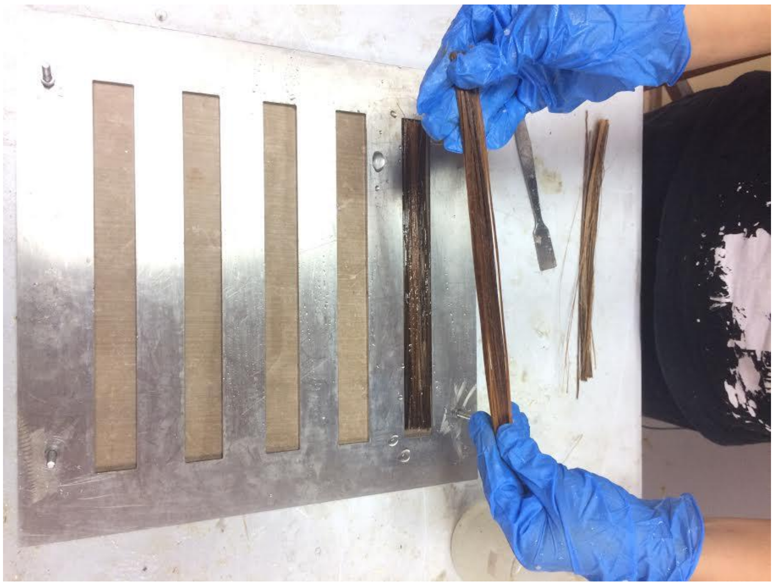


Figure 3.7 Fabricating composite plate with hand lay-up method.

3.5 Preparation of RC Beams

Eight reinforced concrete beams were prepared in this research, including three solid controlled beams and five beams were designed to be deficient in flexure by removing the shear reinforcement in the flexural zone. From the five RC beams without shear reinforcement in the flexure zone, three of them were un-strengthened with BFRCP while the other two were strengthened with BFRCP. The preparation work of specimens was carried out in Concrete Laboratory, Faculty of Civil Engineering (FKASA).

3.5.1 Formwork Preparation

Plywood and wood were used to prepare the formworks for concrete beams because of the light weight, economical and readily available in FKASA concrete lab. The size of the concrete beam was with rectangular section of 100 mm x 130 mm and the total length of 1600 mm. A total of eight formworks with desired dimension were assembled before the concreting work can be proceeded. All the formworks must in good condition and ensure there will be no leakage. A layer of mould oil must be applied at the inner surface before concreting to ease the demould process after the concrete hardened.

Figure 3.8 Sealing of formwork.

3.5.2 Steel Reinforcement

For the reinforcement of beam, the main bar with diameter of 10 mm was used while 6 mm steel bar was used for links. Two diameter 10 mm bars were reinforced for tension and compression respectively and the shear links were placed with spacing of 300 mm center to center. Figure 3.9 shows the schematic diagram for RC control beam.

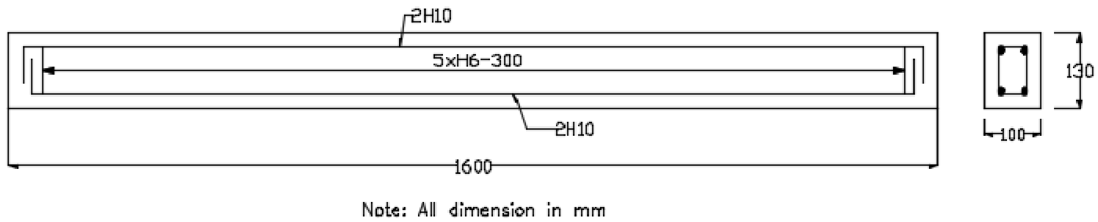


Figure 3.9 Schematic diagram for RC control beam.

3.6 Concreting

In this research, ready-mixed concrete was used to cast the beams to ensure the quality of all the beams were same. The design strength of the ready mixed concrete for 28 days was 30 N/mm^2 supplied by PAMIX Sdn. Bhd as shown in Figure 3.10.

Figure 3.10 Ready mixed concrete from PAMIX Sdn. Bhd.

3.6.1 Casting

Prior to the concrete casting, all the necessary checking must be done. Firstly, inspection on the formwork to ensure no gaps or holes observed, which may cause the leakage during concrete placement. If any, rectification of the formwork must be carried out by using a sealant. Subsequently, cleaned the formwork with air compressor to ensure no debris in the formwork and the casted concrete in good surface quality. Next, applied a layer of mould oil to ease the demould process. Inspection of the steel reinforcement bar was carried out to ensure the works are followed to the specifications. Then, checking on the concrete covers to avoid steel bar exposure as shown in Figure 3.11.

In addition, all relevant equipment and tools to handle concrete pouring are ready. The grade and amount of the concrete, which stated in delivery order have been checked upon delivery of concrete. The slump test and sampling of 12 cubes with the standard dimension mould of 150 mm x 150 mm x 150 mm has been done in advance as shown in Figure 3.12.

During casting, the placing must be started at the corner of formworks. Concrete vibrating must be carried out simultaneously with the concrete placement to avoid honeycomb. The vibrator was vertically inserted and removal within 5 seconds to 30 seconds to avoid excessive vibration which will lead to segregation. Avoid the contact between vibrator and formwork because this might loosen the formwork and affected the quality of concrete.

The beams were covered with canvas after done pouring the concrete to avoid the speedy drying process of concrete which will affect the strength as shown in Figure 3.14.

Figure 3.11 Spacer blocks tied with rebars.

Figure 3.12 Concrete cubes sample for compressive strength tests.

Figure 3.13 Slump test to identify the workability of fresh concrete.

Figure 3.14 Cover the beam with canvas after pouring of concrete.

3.6.2 Curing

After 24 hours, the cast beams were demolded from timber formworks. The beams were further curing for 28 days by using wet gunny bags covered on the surface of RC beams. This is to make sure all the beams have sufficient curing period to develop required strength. The gunny bags were wetting periodically as shown in Figure 3.15. After that, the RC beams were painted with white colour and gridlines were drawn with spacing of 50 mm to ensure all the cracks looked during experiment. The nine concrete cubes were demoulded and put into the water tank for curing purpose immediately after 24 hours of casting.

Figure 3.15 Wetting of gunny bags periodically.

3.7 BFRCP Strengthening System

In this research, the load deflection behaviour and crack patterns of the RC beam strengthened externally at the mid-span bottom soffit was aimed to be achieved. Four-points loading test was used to achieve the objectives.

3.7.1 BFRCP Strengthening at the Flexure Zone of RC Beam

BFRCP with dimension of 100 mm x 450 mm with thickness of 6 mm were strengthened externally at the flexure zone of the beam. Before bonding the composite plate onto the concrete surface, the required region of the concrete surface was roughed and then cleaned with air blower to remove all dirt and debris. This step is important in order to improve the bonding between the concrete beam and composite plate. Sikadur-30 epoxy was used to bond the plate and concrete surface. The component A and B of Sikadur-30 was mixed about 5 minutes to mix evenly. Then, BFRCP was bonded to the respective position and pressed from the middle of plate and then to side to ensure the epoxy was distributed evenly to form better bonding and with a uniform thickness of 3 mm. After seven days curing, the beam can proceed with the next testing.

Figure 3.16 Roughening surface of RC beams.

3.8 Laboratory Testing

3.8.1 Density Test of Bamboo

The test specimens were taken from different positions of the culm (base, middle and top). The bamboo was cut into small pieces with dimension of 20 mm by 20 mm and perfect wall thickness as shown in Figure 3.17. The green volume (V) was measured by water displacement method as shown in. Then the test specimens were dried with oven for 24 hours at 103 ºC to obtain the oven dry mass (m). Basic mass per volume was calculated for each of the 5 samples individually.

Figure 3.17 Samples for density test.

Figure 3.18 Water displacement method for determining the green volume.

3.8.2 Mechanical Properties Test on *Beting* Bamboo

Tensile and compression tests were carried out to identify the mechanical properties of *Beting* bamboo in raw and dried conditions.

3.8.2.1 Compression Test

The compression test was conducted on hollow bamboo culms. Compression test was performed to determine the behaviour of the bamboo after exerted with load.

A total of 6 specimens with dimension of 300 mm length with one node in between were prepared which included 3 raw bamboo and 3 oven-dried bamboo. The oven-dried bamboos were put into oven for 24 hours with 103ºC. The ends were cut properly to ensure a smooth surface for a uniform stress application over the entire cross-section. A universal testing machine (UTM) as shown in Figure 3.19 was used to test the ultimate compressive load of bamboo with a loading rate of 0.05 kN/s for all specimens.

Stress and strain values were calculated and graphs were plotted for each specimen. The equation of cross-sectional area can be obtained from Equation 3.1.

$$A = \frac{\pi}{4}(\{D^2 - (D - 2t)^2\} \qquad 3.1$$

Figure 3.19 Compressive strength test of bamboo using UTM.

3.8.2.2 Tensile Test

The tensile test was tested on bamboo splints to determine the ultimate tensile strength of the bamboo. The ultimate tensile strength of bamboo is of utter importance to calculate the maximum allowable tensile stress in bamboo.

A total of 6 specimens with dimension of 600 mm length, 20 mm width and one node present were prepared which included 3 of raw bamboo and 3 of oven-dried bamboo. The oven-dried bamboos were put into oven for 24 hours with 103ºC. A tensile load was applied with loading rate of 0.05 kN/s on the cross section of all specimens individually on a universal testing machine (UTM) as shown in Figure 3.20.

Stress and strain values were calculated and graphs were plotted for each specimen. The equations of the tensile stress and strain were shown in Equation 3.2 and Equation 3.3.

$$Stress\ (\sigma) = \frac{Load\ (P)}{Cross-sectional\ area\ (A)} \tag{3.2}$$

$$Strain\ (\varepsilon) = \frac{Displacement\ (\Delta)}{Gauge\ Length\ (L)} \tag{3.3}$$

Figure 3.20 Tensile strength test of bamboo using UTM.

3.8.3 Mechanical Properties Test on BFRCP

Mechanical test is a study of the behaviour of a material subjected to loading. The following tests were carried out to identify the mechanical properties of the specimens.

3.8.3.1 Tensile Strength Test (ASTM D3039)

Tensile test was done by using Universal Testing Machine Equipment with a capacity of 5 kN. The composite plates were prepared in accordance standard ASTM D3039 with fiber ratios of 40%. The stainless-steel moulds were used to fabricate BFRCP into a dimension of 250 x 25 mm and thickness of 5 mm for tensile test.

The ends of composite plate were applied with a uniaxial load with a speed of 5mm/min. The ultimate load was recorded and the stress-strain graph was plotted based on the test results. The tensile strength and strain can be obtained from the Equation 3.4 and Equation 3.5.

$$Stress\ (\sigma) = \frac{Load\ (P)}{Cross - sectional\ area\ (A)} \tag{3.4}$$

$$Strain\ (\varepsilon) = \frac{Displacement\ (\Delta)}{Gauge\ Length\ (L)} \tag{3.5}$$


Figure 3.21 Tensile test for BFRCP.

3.8.3.2 Flexural Strength Test (ASTM D709-03)

Figure 3.22 shows the conducted of flexural strength test using Universal Testing Machine (UTM) Equipment with a capacity of 5 kN. The composite samples were prepared in accordance standard ASTM D790-03 with fiber ratios of 40%. The size of composite plates for flexural test were in the dimension of 127 x 12.7 mm, and 6 mm thick.

Three-point loading was used in this test where the load imposed to the mid-span of the samples until it failed. The ultimate load was recorded and the stress-strain graph can be obtained from the test. The flexural strength and strain can be calculated by using Equation 3.6 and Equation 3.7.

$$Stress\ (\sigma) = \frac{3PL}{2bd^2} \quad 3.6$$

$$Strain\ (\epsilon) = \frac{6Dd}{L^2} \quad 3.7$$

where:

P	= Maximum load (N)
L	= Distance between loading points (mm)
b	= Sample width (mm)
t	= Sample thickness (mm)
D	= Displacement (mm)

Figure 3.22 Flexural test for BFRCP.

3.8.4 Four Points Loading Test

Four points loading test were conducted to determine the behaviour of RC beams both strengthened and un-strengthened condition with BFRCP. The optimum fiber volume ratio of 40% was used to fabricate the composite plates and bonded it using Sikadur® 30 resin to the bottom soffit of the beam at the mid-span zone of RC beams. The bonded BFRCP was fully cured for 7 days before proceeding for experimental testing.

The four points test comprises of two loading points and two support points. The load imposed vertically downward until the beam failure. This test was conducted using a Magnus Frame with a capacity ranges of 300 kN to 500 kN. Linear variable displacement transducers (LVDT) was installed at the mid span of solid RC beams to determine the deflection of the beam. The LVDT that attached to the tested beams was connected to a data logger to obtain the deflection value throughout the testing. The crack propagation and crack load were marked on the beam surface for recording purpose. The test lasted until the beam failed and then the results obtained are compared with the control beam.

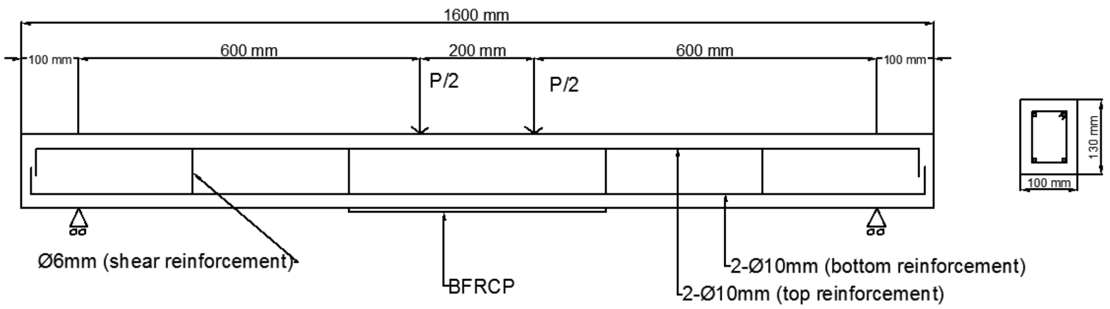


Figure 3.23 Schematic diagram of four-point loading.

Figure 3.24 Four-point loading test setup.

3.9 Summary

Table 3.1 Summary of the numbers of composite plate and sample considered in this study.

Experimental Tests		Condition				Total
		Raw Bamboo	**Oven-dried Bamboo**	**40% fiber volume**	**Pure Composite**	
Bamboo Testing	Tensile Test	3	3	-	-	6
	Compression Test	3	3	-	-	6
	Density Test	5	-	-	-	3
Composite Testing	Tensile Test	-	-	3	3	6
	Flexural Test	-	-	3	3	6
BFRCP for Beam Strengthening	Four-Point Loading Test	-	-	2	-	2

Table 3.2 Summary of beams specimens.

Beam specimen	Beam Dimension (B x H x L) (mm)	Classification	Strengthening Method
1	100 x 130 x 1600	Control Beam (full shear reinforcement)	
2	100 x 130 x 1600		
3	100 x 130 x 1600		
4	100 x 130 x 1600	Beam without shear reinforcement in flexure	-
5	100 x 130 x 1600		-
6	100 x 130 x 1600		-
7	100 x 130 x 1600		Strengthen in Flexure Zone
8	100 x 130 x 1600		Strengthen in Flexure Zone

Table 3.3 Outline of experimental tests included.

Specimens	Experimental tests	
Beting Bamboo	Mechanical and Physical Properties	Tensile Test
		Compression Test
		Density Test
BFRCP	Mechanical Properties	Tensile Test (ASTM D3039)
		Flexural Test (ASTM D709-03)
Strengthened RC Beams with BFRCP	Four-Point Loading Test	

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, all the experimental data obtained are discussed. The tests were divided into three parts which include to determine the behaviour of raw and dried bamboo, behaviour of composite plate based on mechanical and structural behaviour under four-points loading test.

4.2 Properties of Concrete

The proportions in concrete materials such as cement, water and aggregates required are set to meet the specific strength, workability and durability as listed in BS 5328. Slump test and compression test were carried out to identify the performing and quality of concrete is acceptable and reached the targeted concrete strength at 28 days.

4.2.1 Slump Test

The slump obtained was recorded with a height of 103 mm which out of the range of the targeted of 75 ± 25 mm. However, the slump obtained was a true slump, which indicates that high workability of the mixes. Hence, the slump height obtained and concrete quality is still acceptable.

Figure 4.1 Slump test.

4.2.2 Compression Strength Test

The compressive strength of the cured concrete was tested for 3, 7, 14 and 28 days to identify the compressive strength of the concrete for specific day. A total of 12 cubes were prepared for the 4 days testing with 3 cubes for each day to ensure the targeted strength was achieved with a minimum compressive strength of 30MPa at 28 days as shown in Figure 4.2. According to Table 4.1, the compressive strength at day 7 to day 28 had increase gradually and finally reached the target compressive strength. The average compressive strength of cubes at day 7 achieved 85.1% as compared to targeted strength of 30MPa. The mean compressive strength was over-achieved at day 28 which recorded with 31.88MPa, slightly higher than the targeted strength. Hence, the design mix is satisfied the required strength.

Figure 4.2 Compression test.

Table 4.1 Compressive strength of sample cubes.

Sample	Sample Age (Days)	Load (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
A1		255.38	11.35	
A2	3	241.65	10.74	10.84
A3		234.90	10.44	
A4		562.50	25.00	
A5	7	566.55	25.18	25.54
A6		594.68	26.43	
A7		679.73	30.21	
A8	14	662.40	29.44	30.21
A9		697.05	30.98	
A10		725.85	32.26	
A11	28	686.93	30.53	31.88
A12		738.90	32.84	

4.3 Properties of *Beting* Bamboo

The mechanical and physical properties of *Beting* bamboo were identified in this section. Tensile and compression tests were carried out to identify the mechanical properties of raw and dried condition bamboo. For physical properties, density test of bamboo was done to identify the pure density of the bamboo.

4.3.1 Compression Test

Bamboo showed a relative high value of compressive strength. Based on the result obtained, the average compressive strength of raw bamboo was 17.8 % higher than the dried bamboo, which recorded as 33.42 kN and 27.48 kN respectively as shown in Table 4.2. Generally, the mechanical strength of the dried bamboo is higher than that of raw bamboo due to the presence of moisture content in the raw bamboo. In this case, the result obtained is not as the theoretical. This may be due to the over-dried of the bamboo had affected the strength of the bamboo. Addition to that, the different part of the bamboo will affect the mechanical strength of the bamboo. The stronger mechanical strength can be obtained from the middle top part of bamboo (Jusoh, Ahmad and Azmi, 2013). Besides, the thicker the wall of bamboo, the stronger the mechanical strength (Daud *et al.*, 2018). This can be proven in the raw bamboo specimen R3 with the biggest thickness of 8.78 mm recorded with the highest strength of 42.39 MPa. The bamboo specimen showed a mixed mode of failure, which including longitudinal cracking as well as crushing in Figure 4.4.

Table 4.2 Ultimate compressive strength of bamboo.

	Specimen	**Outer diameter, D (mm)**	**Thickness, t (mm)**	**Cross-sectional area, A (mm^2)**	**Crushing load (kN)**	**Crushing strength (MPa)**	**Average crushing strength (MPa)**
Raw	R1	106.08	8.67	2653.22	76.47	28.82	33.42
	R2	107.49	8.51	2646.23	76.89	29.06	
	R3	110.66	8.78	2810.17	119.11	42.39	
Dried	D1	107.76	10.09	3096.01	102.39	33.07	27.48
	D2	113.50	9.34	3056.31	78.18	25.58	
	D3	110.94	8.65	2779.71	66.12	23.79	

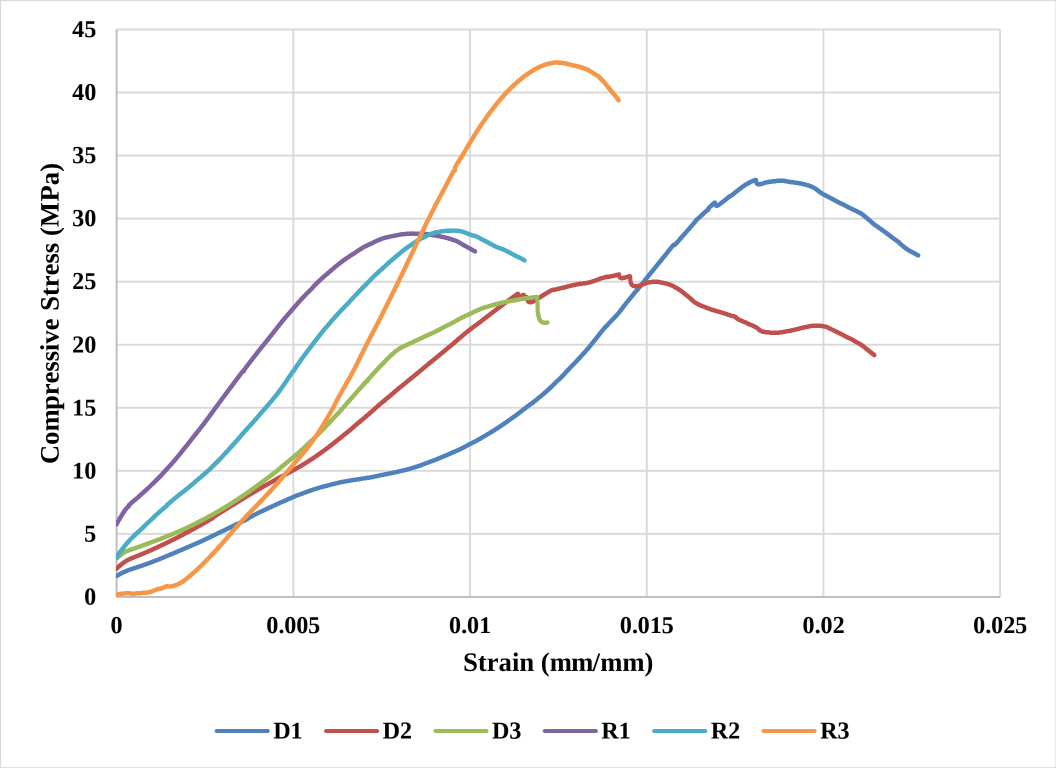


Figure 4.3 Stress vs Strain graph of Compression Test for Raw and Dried bamboo.

Figure 4.4 Cracking and crushing of bamboo.

4.3.2 Tensile Test

The average ultimate tensile strength of bamboo splints of dried bamboo was 27.5% higher than the raw bamboo with a recorded strength of 114.32 MPa and 89.67MPa respectively as listed in Table 4.3. This had proven that the theory of mechanical strength of dried bamboo is higher than the raw bamboo can be accepted. Hence, bamboo can take sufficient tensile loads when fabricated in composite plate.

From Figure 4.6, bamboo specimens shown brittle failure at node which make it the most critical section for failure under tensile stresses. This is because as compared to the internode part of the bamboo where a very dense fibrous matrix is present along the length, there is no fibers present at nodes, only fine granules of wood present at the node, hence the nodes appeared as the beginning and terminating point of fibers. Therefore, when extracting fibers, the nodes part was being cut off to ensure the mechanical strength of fibers will not be affected.

Table 4.3 Ultimate tensile strength of bamboo.

	Specimen	**Width, B (mm)**	**Thickness, t (mm)**	**Cross-sectional area, A (mm^2)**	**Ultimate force (kN)**	**Ultimate tensile strength (MPa)**	**Average Ultimate (MPa)**
Raw	1	22.21	10.26	227.87	20.16	88.49	89.67
	2	22.18	9.47	210.04	21.56	102.63	
	3	22.55	9.85	222.12	17.30	77.89	
Dried	1	23.21	9.4	218.17	22.53	103.29	114.32
	2	20.25	8.98	181.24	20.84	114.96	
	3	20.63	8.90	183.61	22.90	124.71	

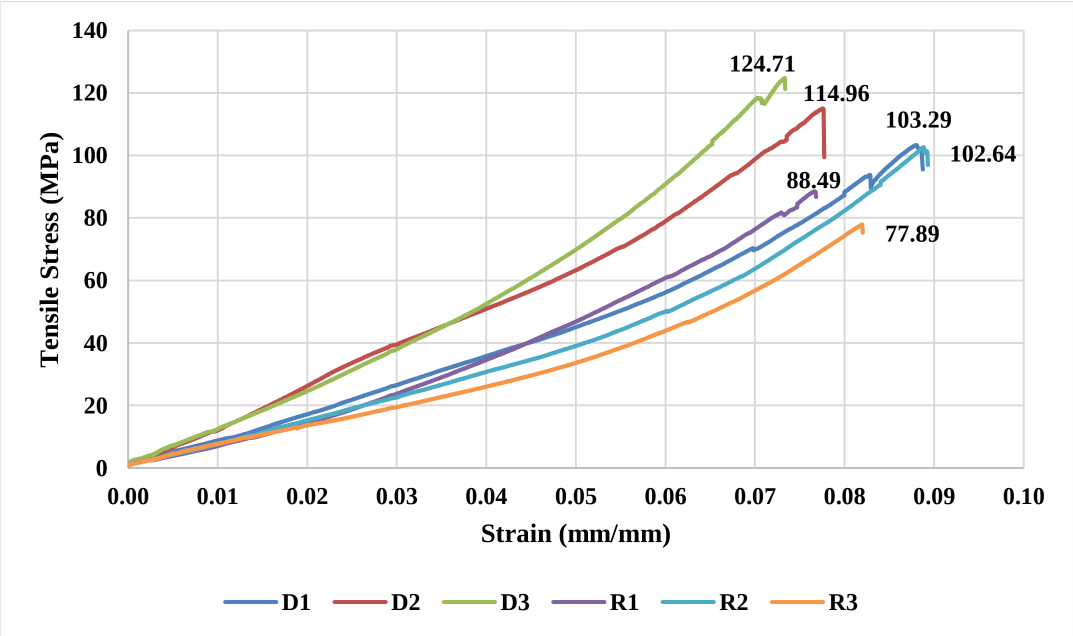


Figure 4.5 Stress vs Strain graph of Tensile Test.

Figure 4.6 Failure of bamboo splint at node under tensile load.

4.3.3 Density Test

From Table 4.4, the density of bamboo lies in the range of 0.5-0.6 g/cm^3. The low density properties of bamboo makes it a very light material which can be transported and worked easily. The density of bamboo was then used for calculating the fiber loading in fabrication of composite plate.

Table 4.4 Density of different specimens.

Specimen No	Oven Dry Mass(g)	Volume of Specimen (cm^3)	Mass Density (g/cm^3)	Average Density (g/cm^3)
1	2.77	4.00	0.69	0.59
2	2.77	5.00	0.55	
3	2.77	5.00	0.55	
4	2.82	5.00	0.56	
5	2.74	4.50	0.61	

4.4 Mechanical Behaviour of Bamboo Fiber Reinforced Composite Plate

Bamboo fiber reinforced composite plates (BFRCPs) were subjected to mechanical properties test to evaluate the flexural and tensile strength of BFRCP. These tests aimed to identify the strength of the bamboo fiber and suitability of bamboo fiber to be used as the reinforced fiber in composite plate as the external strengthening of RC beam. All the fabricated composites were prepared as per ASTM standard. In this present study, the mechanical test that carried out including flexural test (ASTM D790-03) and tensile test (ASTM D3039). The following section discussed all the related mechanical test in details.

4.4.1 Tensile Strength Test (ASTM D3039)

The effect of fiber loading on tensile strength of composite plate had summarized in Table 4.5. From the table, the ultimate tensile strength of the bamboo fiber reinforced composite recorded with a higher average peak load as compared to the neat epoxy composite. There was an increment of 374.59% in term of average ultimate tensile strength for fiber reinforced composite as compared to the un-reinforced composite. The tensile stress for fiber reinforced composite T4, T5 and T6 had increased with the strain linearly until maximum value, followed a sudden drop owning to the final and catastrophic fracture as shown in Figure 4.7. The result of the samples was found to be compatible. However, the ultimate strengths of some specimens were found lacking in consistency which might due to the existence of air entrapment inside the composite plate that affecting the properties of composite plate.

Table 4.5 Tensile strength results.

Sample	Volume Ratio of Fiber (%)	Peak Load (N)	Average Peak Load (N)	Ultimate Tensile Strength (MPa)	Average Ultimate (MPa)
T1	0	2904.88	2877.31	23.24	23.02
T2	0	2716.52		21.73	
T3	0	3010.54		24.08	
T4	40	13330.5	13656.87	106.64	109.25
T5	40	11319.9		90.56	
T6	40	16320.2		130.57	

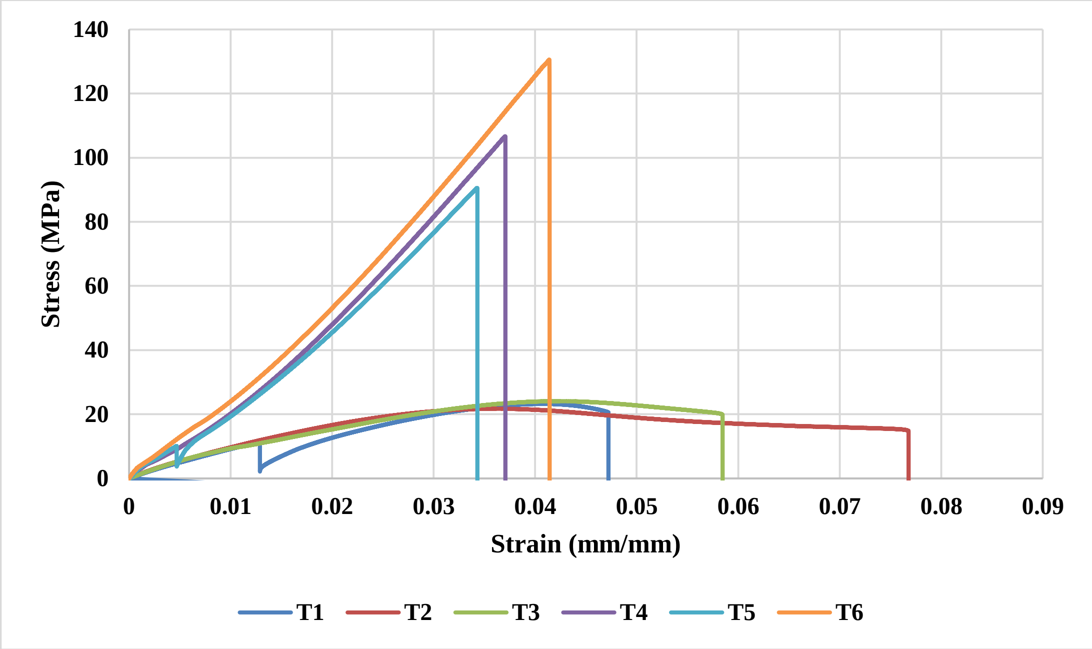


Figure 4.7 Stress-strain graph of tensile test.

4.4.2 Flexural Strength Test (ASTM D709-03)

For flexural strength test, the neat epoxy samples recorded with peak load of 80.38 N, 38.88 N and 56.53 N respectively which is much lower as compared with the 40 % fiber loading samples with peak load of 457.63 N, 411.61 N and 626.10 N respectively as shown in Table 4.6. The average ultimate strength of BFRCP was 11.76 times more than the neat epoxy sample, which increased from 20.57 MPa to 174.98 MPa. The total improvement of 750.6 % for peak load of fiber reinforced composite as compared with the neat epoxy plate, indicating that the fiber reinforced composite plate is more effective than neat epoxy plate.

From Figure 4.8, the stress versus strain curve show inconsistent result for some tested samples. These may have caused by several factors such as the existence of bubbles void in the samples. Bubbles formed during the mixing of epoxy and hardener during the sample fabrication stage which may affect the interfacial adhesion between resin and fibers, whereby reduced the flexural strength of fiber composite plate.

Table 4.6 Flexural strength of three-point bending test.

Sample	Volume Ratio of Fiber (%)	Peak Load (N)	Average Peak Load (N)	Ultimate Flexural Strength (MPa)	Average Ultimate Strength (MPa)
F1	0	80.38		28.22	
F2	0	38.88	58.60	13.65	20.57
F3	0	56.53		19.84	
F4	40	457.63		160.65	
F5	40	411.61	498.45	144.50	174.98
F6	40	626.10		219.79	

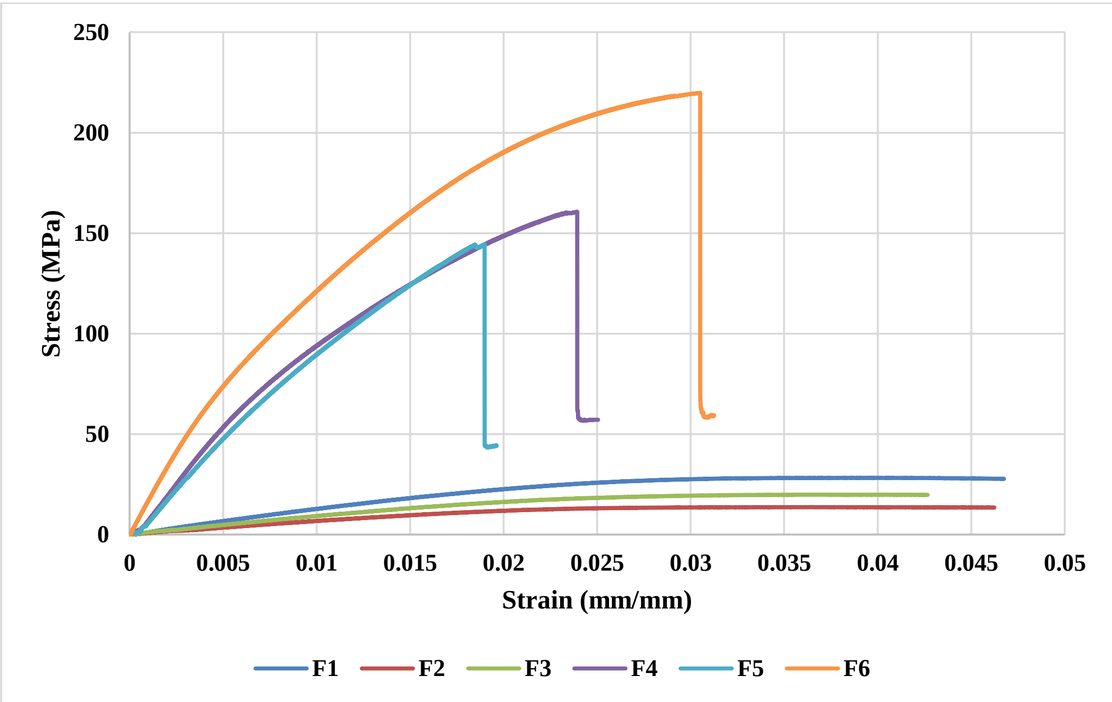


Figure 4.8 Stress-strain graph of flexural test.

4.5 Strengthening behavior of RC Beams in Flexure Zone

Bamboo fiber reinforced composite plate (BFRCP) in dimension of 100 mm in width, 6 mm think and a total length of 450 mm was fabricated with 40% fiber loading. A total of two composite plates were prepared and bonded at the mid-span soffit of RC beams using Sikadur-30 epoxy adhesive. Four-point loading system was adopted for the testing of beams. The ultimate load, deflection, cracks pattern and type of failure were observed and recorded.

4.5.1 Load and Deflection Behaviour

The control beam (CB) and beam without shear link at the flexure zone un-strengthened using BFRCP (UNST) are used to compare with the beam without shear link at the flexure zone strengthened using BFRCP (ST).

Control beam (CB)

At the beginning of the loading, the load was directly proportional to the deflection before reaching the yield point as shown in Figure 4.9. For specimen CB 1 and CB 3, both of them showed an almost similar trend, a sharp drop after achieving an ultimate load which is more brittle than the other specimen. Whereas, for specimen CB 2, a steady upward trend was observed in the strain hardening stage until reaching an ultimate load of 24.70 kN with deflection of 19.8 mm. Upon reaching the ultimate load, the load was then dropped gradually.

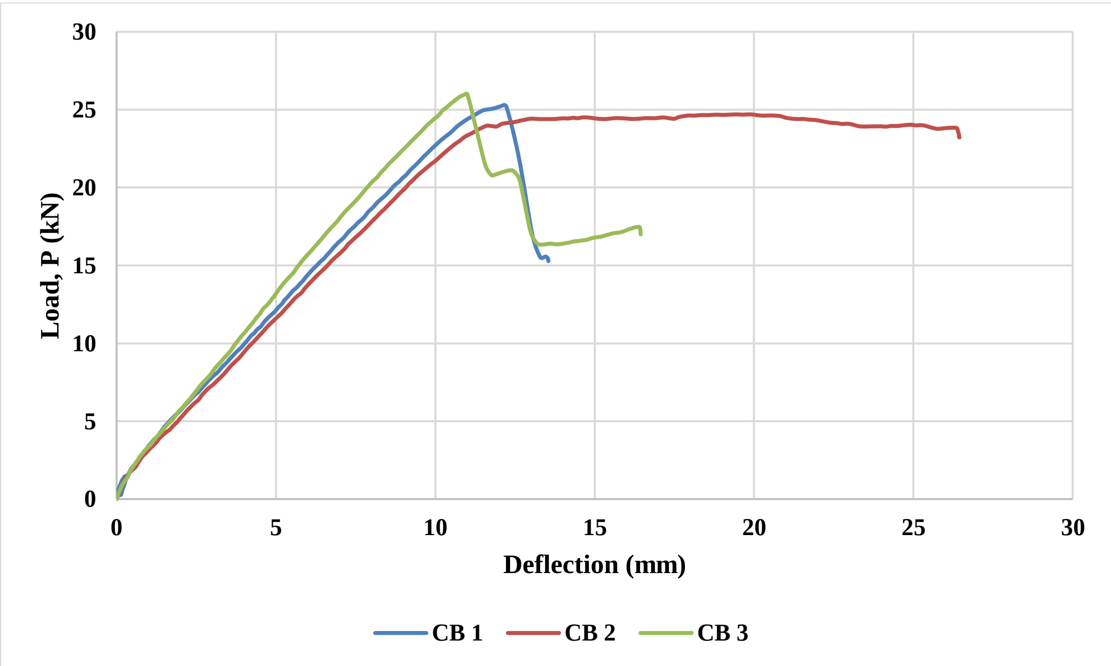


Figure 4.9 Load deflection graph for CB.

Un-strengthened beam (UNST)

From Figure 4.10, three of the specimens had a steep slope upward curve at the initial loading with the load proportional to the deflection. Yet, specimen UNST 3 and UNST 1 showed a higher ultimate load compared to UNST 2 which recorded with 23.04 kN and 21.43 kN respectively. However, specimen UNST 3 and UNST 1 were more brittle than specimen UNST 2 due to the sharp drop upon the ultimate load. The yield point for specimen UNST 2 happened at a load of 15.40 kN and deflection of 6.92 mm and reached an ultimate load of 17.42 kN at 16.97 mm deflection. Beyond the ultimate load, the deflection of the beam was seen increasing appreciably with the load declined dramatically.

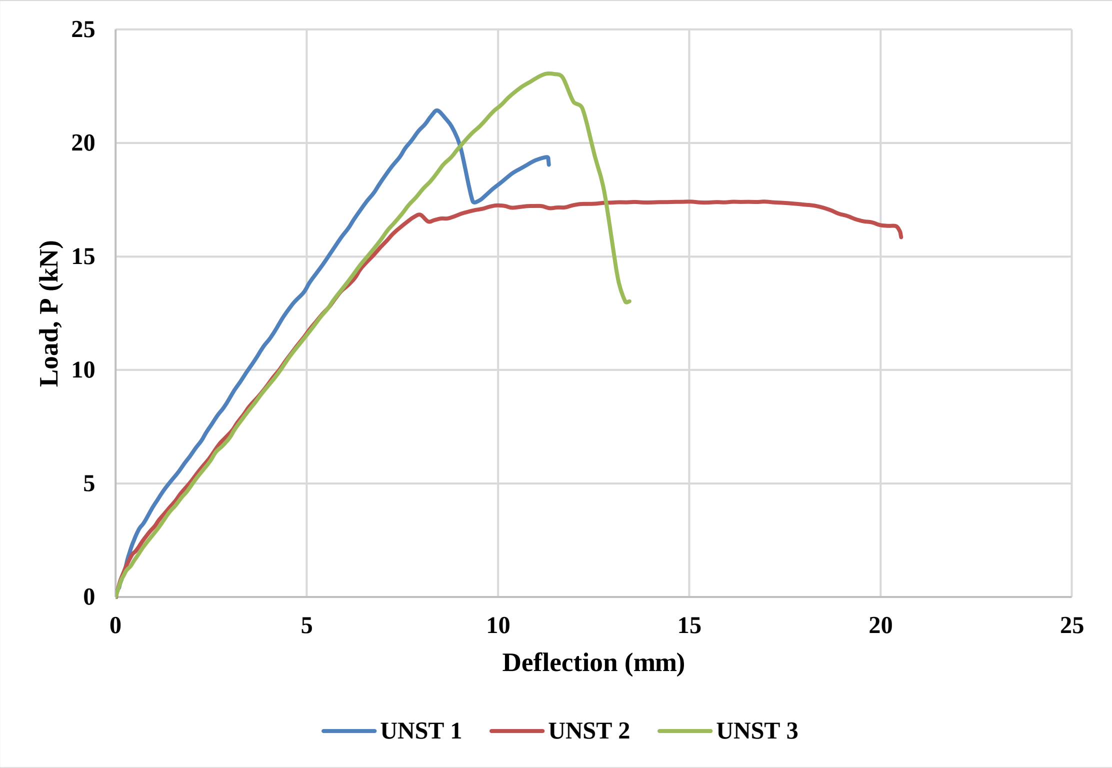


Figure 4.10 Load deflection graph for UNST.

Strengthened beam (ST)

By referring Figure 4.11, both specimens had a similar curve pattern. In the first stage, both ST 1 and ST 2 followed a linear elastic behaviour pattern. The load and deflection of the ST 1 and ST 2 increased linearly up to the yield point of 24.69 kN and 25.01 kN respectively. The ultimate load of ST 2 was 1.92 % slightly higher than the ST 1 specimen with recorded loads of 25.49 kN at deflection of 16.12 mm. The load was then dropped gradually with the increase in deflection. The BFRCP was able to carry the loads that mainly carried by the shear reinforcement at the flexure zone and restore the load to the control beam. The presence of BFRCP prolonged the plastic phases as the load was constant with the increase in deflection indicating higher performance in ductility.

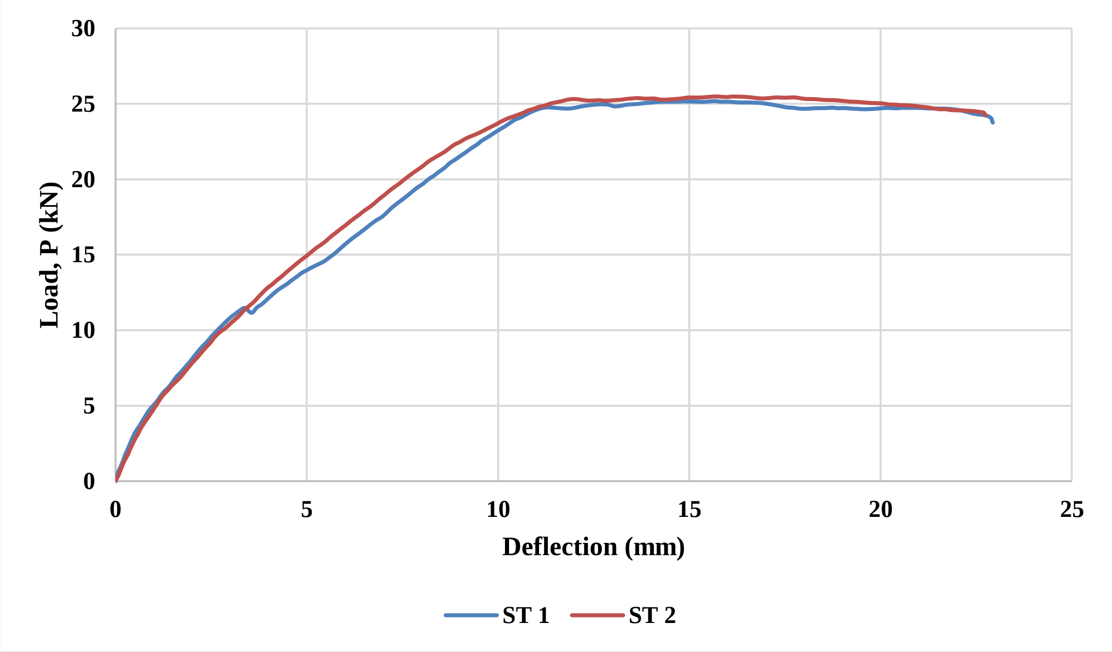


Figure 4.11 Load deflection graph for ST.

Comparison

For the comparison among the specimens, the CB 2, UNST 3, ST 1 and ST 2 were chosen since they had the most significant result and with the most accurate behaviour. Table 4.7 and Table 4.8 had summarized the comparison in terms of ultimate load and deflection at the mid-span beam.

Comparison between CB 2 and UNST 3

By referring Figure 4.12, the specimen CB 2 showed the beam had a higher stiffness compared to the specimen UNST 3 because the load dropped gradually with the deflection after achieved an ultimate load. Whereas, for specimen UNST 3, a sudden steep dropped observed after reaching an ultimate load. Hence, the UNST 3 was much more brittle compared to CB 2. The yield point for UNST 3 was 19.05 kN at deflection of 8.57 mm while the CB 2 achieved yield point later than UNST 3 which was at a deflection of 11.19 mm. In terms of ultimate load, with the omitted shear link in flexure, there was 6.72% of load reduce compared to control beam as shown in Table 4.7.

Comparison between UNST 3 and ST

By comparing the UNST 3 with specimen ST, both the specimen ST 1 and ST 2 showed a higher load capacity compared to UNST 3. According to Table 4.7, there was an increment of 9.30 % and 10.63 % in terms of beam strength for beam ST 1 and ST 2 when comparing with UNST 3. The result indicates that BFRCP managed to enhance the strength of the beam in carry higher loading capacity, however, no significant difference in load increment was traced. This may be due to the span ratio of BFRCP used in strengthening the beams is not sufficient. In order to have significant enhancement in the ultimate load, it is recommended to have a span ratio of BFRCP must be at least equal to or more than $\frac{2}{3}$ of the overall beam's ratio. The deflection of specimens ST 1 and ST 2 were higher than the beam UNST 3 with deflection ratio of 1.37 and 1.41 respectively due to the brittle properties of the specimen UNST. Moreover, the gradual decrease in the load against the deflection after achieved the ultimate load had yield a higher deflection.

Comparison between CB 2 and ST

In comparison, between beam CB 2 and ST, it was found that the strengthened beam is capable to restore the load carrying capacity of the control beam. The beam CB was recorded with an ultimate load of 24.70 kN while beam ST 1 and ST 2 recorded with an ultimate load of 25.18 kN and 25.49 kN respectively. This indicates that there was in increase in load of 1.91 % and 3.10 % for ST 1 and ST 2 respectively as compared with CB 2. In terms of deflection, the strengthened specimens ST 1 and ST 2 had the capability to reduce the deflection by 21 % and 18.7 % as compared with the CB 3.

Table 4.7 Comparison in terms of ultimate load.

Specimen	**Ultimate Load (kN)**	**Strengthening Ratio**	
CB 2	24.70	1.00	
UNST 3	23.04	0.93	compared to CB 2
ST 1	25.18	1.09	compared to UNST 3
		1.02	compare to CB 2
ST 2	25.49	1.11	compared to UNST 3
		1.03	compare to CB 2

Table 4.8 Comparison in terms of deflection.

Specimen	Deflection at Ultimate Load (mm)	Deflection Ratio	
CB 2	19.82	1.00	
UNST 3	11.46	0.58	compared to CB 2
ST 1	15.66	1.37	compared to UNST 3
		0.79	compare to CB 2
ST 2	16.12	1.41	compared to UNST 3
		0.81	compare to CB 2

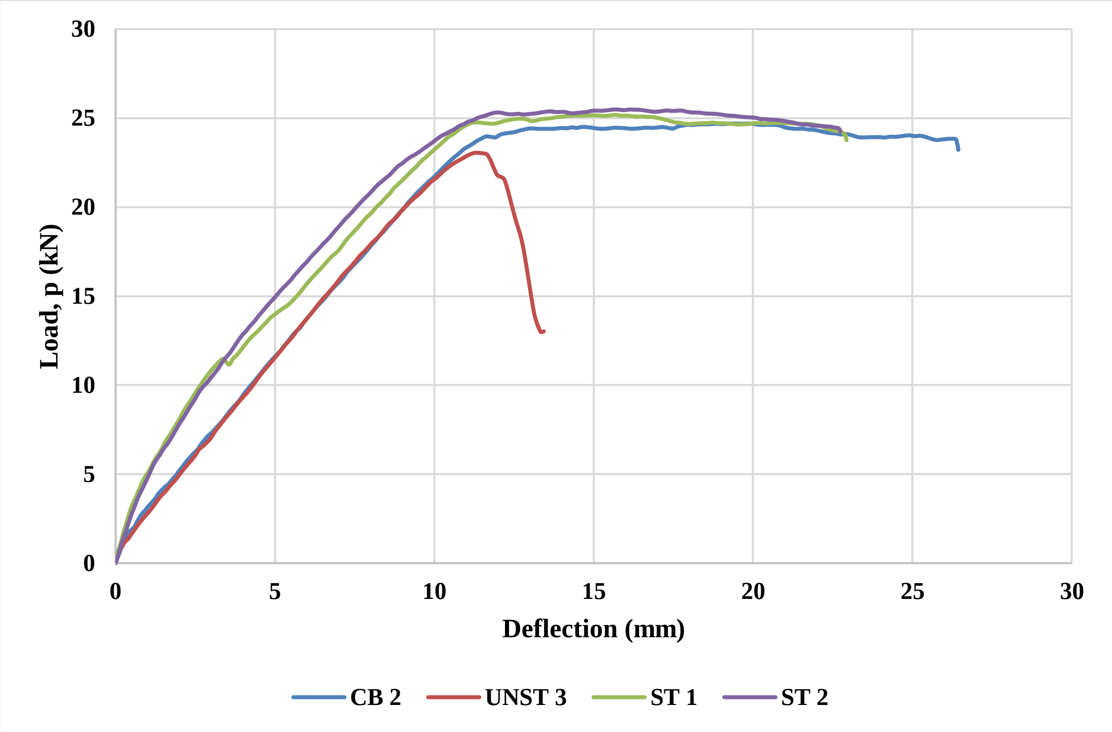


Figure 4.12 Load deflection curve of different beam specimens.

4.5.2 Crack patterns

Figure 4.13 to Figure 4.15 show the crack patterns of control beams. From the three figures, it was observed that all the vertical cracks concentrated at the mid span of the beam, as would be expected for flexural cracks. At the initial stage of loading, vertical cracks can be seen along the tension zone with the first crack at about 7 kN and propagated to the neutral axis. For specimen CB 1 and CB 2, the cracks were propagated towards the support and diagonal shear cracks were observed.

Figure 4.16 to Figure 4.18 illustrate the crack patterns for un-strengthen beam. Based on the observation, more vertical cracks were formed along the tension zone as compared to the control beam due to the removal of shear link at the flexural zone. The first crack determined at load about 4 kN. For specimen UNST 3, a diagonal shear crack was observed.

For the strengthen beams using BFRCP, they are shown in Figure 4.19 and Figure 4.20. For ST 1 which is shown in Figure 4.19, the BFRCP enhances the beam strength and reducing the cracks by resisting the tensile stresses in the tension zone and diverted the flexure cracks to diagonal cracks at the edge of plate. The first vertical crack at load of 4 kN was observed at the both edge sides of the strengthening plate. The vertical cracks then propagated with the increased of load until the neutral axis of the. A wide diagonal crack width was detected at the right side of the beam upon beam failure. This may due to the imperfection bonding between BFRCP and the RC beam which affect the transfer of load in the beam.

By referring to Figure 4.20, the crack patterns were found almost similar with the beam ST 2 which was a little vertical crack along the tension zone since the strengthening plate had diverted the cracks to the edge of the plate. At load of 7 kN, the crack was formed at the edge of the strengthening plate due to the effective strengthening of BFRCP.

Figure 4.13 Crack patterns for CB 1.

Figure 4.14 Crack patterns for CB 2.

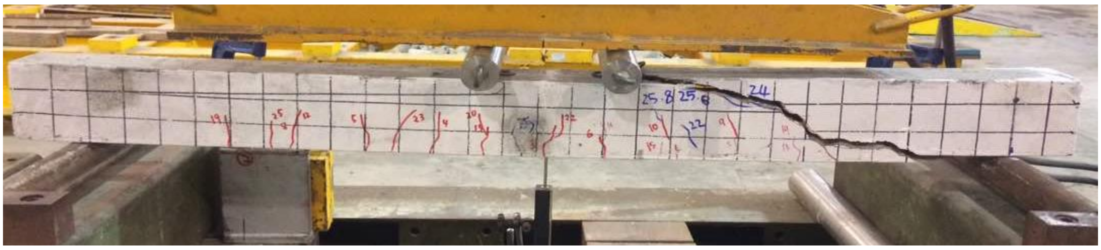


Figure 4.15 Crack patterns for CB 3.

Figure 4.16 Crack patterns for UNST 1.

Figure 4.17 Crack patterns for UNST 2.

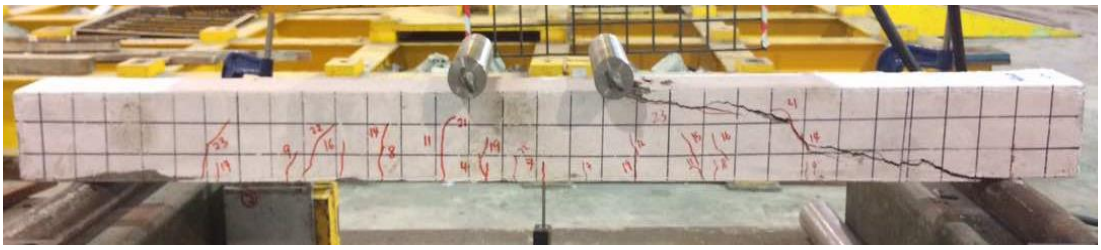


Figure 4.18 Crack patterns for UNST 3.

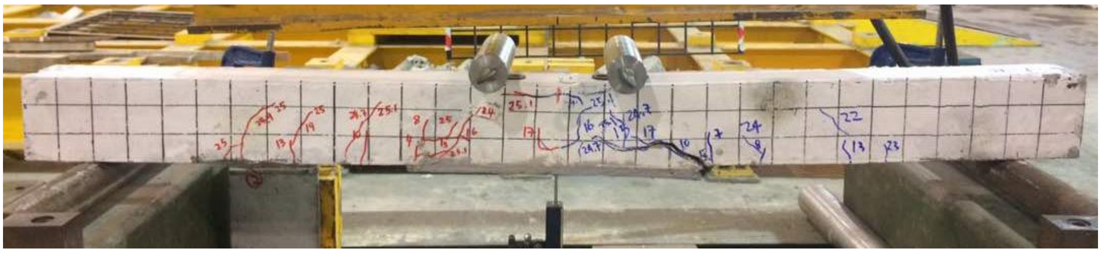


Figure 4.19 Crack patterns for ST 1.

Figure 4.20 Crack patterns for ST 2.

4.5.3 Failure mode

Vertical cracks were formed during the application of load. The four-point loading test was halted once the RC beams experienced flexural failure. Table 4.9 summarizes the failure modes of the solid beam specimens during the test.

Table 4.9 Failure modes of beam specimens.

Specimen	Failure mode	Sequence of failure mode	Remarks
CB	Flexural	Vertical crack. Concentrated cracks at mid-span. Beam failed gradually. Concrete crushing.	Normal failure mode of RC beams.
UNST	Flexural	Vertical crack. Concentrated cracks at mid-span. Concrete crushing.	Normal failure mode of RC beams.
ST	Flexural	Vertical crack at the edge of BFRCP. Mild cracks at mid-span. Diagonal crack Concrete crushing.	Normal failure mode of RC beams.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter summarizes all the discussions and results of this research. The mechanical properties of the bamboo fiber reinforced composite plate (BFRCP) were investigated as well as the effective strengthening of BFRCP in flexure of RC. At the end of the chapter, recommendation for future work references are listed.

5.2 Conclusion

Based on the result obtained and discussed, the objectives are achieved throughout the experimental works. Several conclusions can be drawn based on the results discussed:

i. For the mechanical properties of raw and dried bamboo, the compressive strength of the raw bamboo obtained was 17.8 % higher than the dried bamboo. In fact, the strength of the dried bamboo should be higher than the raw bamboo due to the moisture content in the raw bamboo. This might be due to the over-dried of the bamboo which affected the strength of the bamboo. In tensile strength test, the tensile stress of the dried bamboo was 27.5 % higher than the raw bamboo which comply with the fact. The bamboo specimen shown brittle failure at node which denoted as the most critical section for failure under tensile stresses. Hence, the node part has to be avoided during the fiber extraction.

ii. In terms of mechanical properties of composite plate, it was found that both flexural strength and tensile strength of BFRCP recorded with higher value as compare with the neat epoxy specimens with 374.59 % and 750.60 % respectively. as compare with the neat epoxy specimens with 374.59 % and 750.60 % respectively. Addition to that, it was proven by past researchers that 40% fiber volume loading is the optimum ratio, which gives the highest mechanical strength for composite plate. Hence, 40% fiber volume ratio was used in composite plate as the external strengthening plate for RC beam.

iii. Strengthened RC beams with BFRCP increased the strength of the beam approximately by 9.30 % and 10.63 % respectively when compared with the beam UNST which reduced the load carrying capacity of about 6.72 % of control beam. In comparison between beam CB and ST, it was found that the strengthened beam using BFRCP managed to restore the load carrying capacity of the control beam. In terms of crack pattern, vertical flexural cracks were found along the tension zone in the mid-span of the control beam and un-strengthen beam. However, concentrated vertical cracks in the un-strengthened beam were traced compared to the control beam as shear link at the mid-span had been eliminated. Apart from that, bamboo fiber reinforced composite plate had diverted the cracks from mid-span of beam to the edge of the strengthening plate causing the formation of diagonal cracks.

5.3 Recommendation

Recommendations were listed as below for enhancement of bamboo fibers reinforced composite plate performance:

i. In order to obtain a significant improvement in the tension zone of RC beam, the span ratio of BFRCP must be equal to or greater than two third of the total length of the beam.

ii. Single fiber test should be conducted since the measurement of the tensile strength of the individual bamboo fiber to determine the performance of a single fiber.

5.4 Limitation of Current Research

In the present study, it was difficult to obtain long bamboo fiber in excess of 450 mm due to the presence of nodes in bamboo that resulting in a weak strength which could affect the properties of bamboo fiber and fabrication of composite plate. Therefore, the span of BFRCP used in flexural strengthening was limited and only showed a little increment in the ultimate load compared to the control beam.

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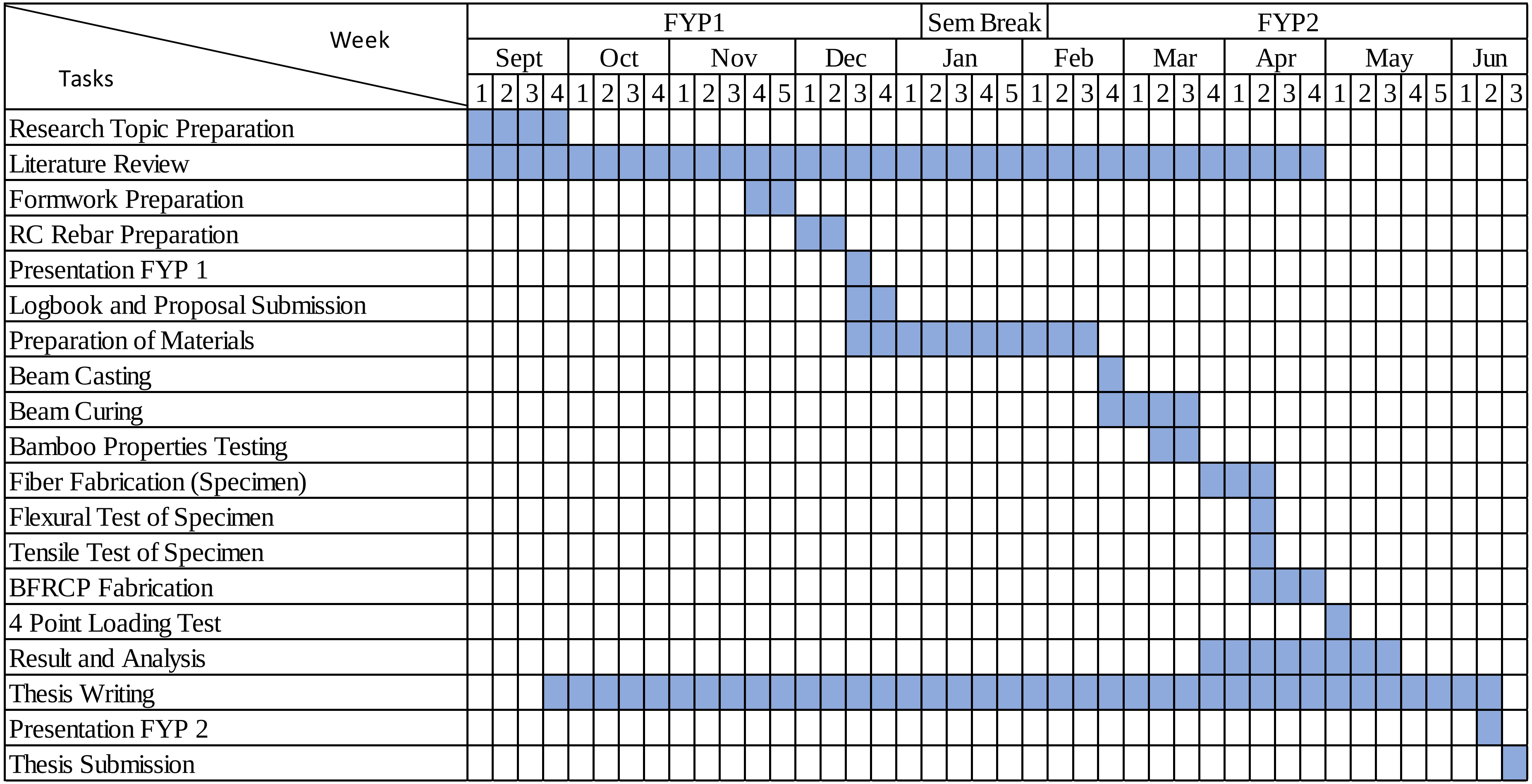
APPENDIX A
GANTT CHART



APPENDIX B
CALCULATION BY VOLUME FOR DIFFERENT FIBER LOADING OF BFRCP

Calculation of Fiber Composite Plate Material

Formula:

Mass of Fiber = Density of Fiber x Volume of Plate x Fiber ratio
Mass of Resin = Density of Resin x Volume of Plate x (1- Fiber Ratio)
Mass of Epoxy = Mass of Resin x part of Epoxy in ratio
Mass of Hardener = Mass of Resin - Mass of Epoxy

Tensile Specimen

Density of Bamboo Fiber	=	0.59 g/cm3
Density of Epoxy Resin	=	1.16 g/cm3
Dimension of Composite Plate	=	250 x 25 x 5 mm
Volume of the Plate	=	31.25 cm3

Fiber volume ratio

Fiber (%)	Weight of fiber (g)	Resin (%)	Weight of Epoxy (g)	Weight of hardener (g)
0.00	0.00	100.00	24.17	12.08
40.00	7.38	60.00	14.50	7.25

Strengthening Plate

Density of Bamboo Fiber	=	0.59 g/cm3
Density of Epoxy Resin	=	1.16 g/cm3
Dimension of Composite Plate	=	450 x 100 x 6 mm
Volume of the Plate	=	270 cm3

Fiber volume ratio

Fiber (%)	Weight of fiber (g)	Resin (%)	Weight of Epoxy (g)	Weight of hardener (g)
40.00	63.72	60.00	125.28	62.64

Flexural Specimen

Density of Bamboo Fiber	=	0.59 g/cm3
Density of Epoxy Resin	=	1.16 g/cm3
Dimension of Composite Plate	=	127 x 12.7 x 6 mm
Volume of the Plate	=	9.6774 cm3

Fiber volume ratio

Fiber (%)	Weight of fiber (g)	Resin (%)	Weight of Epoxy (g)	Weight of hardener (g)
0.00	0.00	100.00	7.48	3.74
40.00	2.28	60.00	4.49	2.25

APPENDIX C
DATA SHEET OF EPOXY D.E.R. 331

Ingestion: Use good personal hygiene. Do not consume or store food in the work area. Wash hands before smoking or eating.

Engineering Controls
Ventilation: Good general ventilation should be sufficient for most conditions.

9. Physical and Chemical Properties

Physical State	Liquid
Color	White to yellow
Odor	Mild
Flash Point - Closed Cup	252 °C *PMCC, ASTM D93*
Flammable Limits In Air	**Lower**: Not applicable **Upper**: Not applicable
Autoignition Temperature	Not applicable
Vapor Pressure	Not applicable
Boiling Point (760 mmHg)	Not applicable.
Vapor Density (air = 1)	Not applicable
Specific Gravity (H2O = 1)	1.16 *Literature*
Liquid Density	1.156 - 1.166 g/cm3 @ 25 °C *ASTM D4052*
Freezing Point	Not Determined
Melting Point	Not Determined
Solubility in Water (by weight)	Insoluble
pH	Not Determined
Dynamic Viscosity	11,000 - 13,500 mPa.s @ 25 °C *ASTM D445*

10. Stability and Reactivity

Stability/Instability
Stable under recommended storage conditions. See Storage, Section 7.
Conditions to Avoid: Avoid temperatures above 300°C (572°F) Potentially violent decomposition can occur above 350°C (662°F) Generation of gas during decomposition can cause pressure in closed systems. Pressure build-up can be rapid.

Incompatible Materials: Avoid contact with oxidizing materials. Avoid contact with: Acids. Bases. Avoid unintended contact with amines.

Hazardous Polymerization
Will not occur by itself. Masses of more than one pound (0.5 kg) of product plus an aliphatic amine will cause irreversible polymerization with considerable heat build-up.

Thermal Decomposition
Decomposition products depend upon temperature, air supply and the presence of other materials. Gases are released during decomposition. Uncontrolled exothermic reaction of epoxy resins release phenolics, carbon monoxide, and water.

11. Toxicological Information

Acute Toxicity
Ingestion
Very low toxicity if swallowed. Harmful effects not anticipated from swallowing small amounts.
LD50, Rat > 5,000 mg/kg
Eye Contact

APPENDIX D
DATA SHEET OF HARDENER JOINTMINE 905 – 3S

EPOCHEMIE

An associate company of Yun Teh Industrial Co., Ltd

Product Data Sheet

LIT/0508-905-3S

JOINTMINE 905-3S

INTRODUCTION

JOINTMINE 905-3S is a modified cycloaliphatic amine of low viscosity, low color and room temperature curing agent. It imparts good resistance to abrasion, moisture and chemical resistance. It has also low in toxicity than aliphatic amine and exhibit high gloss film and ideal for solventless free floor coating, self-leveling flooring and tank lining.

CHARACTERISTICS

- Low viscosity and transparent liquid
- Good working pot life
- Good chemical resistance
- High gloss and good color stability

APPLICATIONS

- Self-leveling floor coating
- High solid coating
- Chemical tank coating
- Water resistant tile grout

PACKING

Jointmine 905-3S available in 200kg net per drum

STORAGE CONDITIONS

At least 12 months from the date of manufacture in the original sealed container at ambient temperature. Store away from excessive heat and humidity in tightly closed containers.

SPECIFICATION

Amine value (mg KOH/g)	300 ± 20
Viscosity (BH type @25°C, cPs)	200 ~ 400
Color (Gardner)	<2
Equivalent Wt (H)	95

BASIC FORMULATION

Mix ratio (with EEW=190 epoxy resin) = 50 phr

TYPICAL PROPERTIES

Pot life (100g @25°C)	75 mins
Hardness (Shore D)	85
Thin film set time (@25°C)	5 hours

PHYSICAL PROPERTIES

Compressive Strength (JIS K6911)	1000kg/cm^2
Bending Strength (JIS K6911)	800kg/cm^2
Tensile Strength (JIS K6911)	700kg/cm^2

Epochemie International Pte Ltd., No.1, Woodlands Terrace, Singapore 738471
Tel : 65-67565680 Fax : 65-67560760, email : epochemie@pacific.net.sg

APPENDIX E
DATA SHEET OF SIKADUR® 30 EPOXY LAMINATING RESIN

Product Data Sheet
Edition 01/02/2012
Identification no:
01 04 01 04 001 0 000001
Sikadur®-30

CE

Construction

Sikadur®-30

Adhesive for bonding reinforcement

Product Description

Sikadur®-30 is a thixotropic, structural two part adhesive, based on a combination of epoxy resins and special filler, designed for use at normal temperatures between +8°C and +35°C.

Uses

Adhesive for bonding structural reinforcement, particularly in structural strengthening works. Including:

- Sika® CarboDur® Plates to concrete, brickwork and timber (for details see the Sika® CarboDur® Product Data Sheet, the "Method Statement for Sika® CarboDur® Externally Bonded Reinforcement" Ref: 850 41 05 and the "Method Statement for Sika® CarboDur® Near Surface Mounted Reinforcement" Ref: 850 41 07).
- Steel plates to concrete (for details see the relevant Sika® Technical information).

Characteristics / Advantages

Sikadur®-30 has the following advantages:

- Easy to mix and apply.
- No primer needed.
- High creep resistance under permanent load.
- Very good adhesion to concrete, masonry, stonework, steel, cast iron, aluminium, timber and Sika® CarboDur® Plates.
- Hardening is not affected by high humidity.
- High strength adhesive.
- Thixotropic: non-sag in vertical and overhead applications.
- Hardens without shrinkage.
- Different coloured components (for mixing control).
- High initial and ultimate mechanical resistance.
- High abrasion and shock resistance.
- Impermeable to liquids and water vapour.

Tests

Approval / Standards

Deutsches Institut für Bautechnik Z-36.12-29, 2006: General construction authorisation for Sika® CarboDur®.

IBMB, TU Braunschweig, test report No. 1871/0054, 1994: Approval for Sikadur®-30 Epoxy adhesive.

IBMB, TU Braunschweig, test report No. 1734/6434, 1995: Testing for Sikadur®-41 Epoxy mortar in combination with Sikadur®-30 Epoxy adhesive for bonding of steel plates.

Testing according to EN 1504-4

APPENDIX F
CONCRETE MIX DESIGN COMPUTATION & SUMMARY

PAMIX SDN BHD	**PAMIX SDN. BHD.** (Company No. 261694-H) A-9, 2ND & 3RD Floor, Pusat Komersial Kuantan Perdana, Jalan Tun Ismail, 25000 Kuantan, Pahang, Darul Makmur. Tel : 09-5172810 / 2813 / 2819 Fax : 09-5172821 / 2806 (A/C)	Document No. Revision No. Effective Date Page No.	: PSB-F-QA-01-02 : 0 : 01/04/2017 : 1 of 1

CONCRETE MIX DESIGN COMPUTATION & SUMMARY

Reference Standard : For Specifying Production And Compliance Creteria
(MS523: 1993 / BS 5328 / JKR 20800 - 0183 - 14 " Standard Specifications for Building Works 2014")

1	1.1	Characteristic Strength (OPC)	Specified **30 N/mm2 at 28 days** below which 5 % of test results may be expected to fall	
	1.2	Designed Standard Deviation	4 N/mm2	
	1.3	Designed Margin	1.64 * = 6.56 N/mm2	
	1.4	Target Mean Strength	**37.0 N/mm2**	
	1.5	Cement Type	OPC	
	1.6	Cement Source	PAHANG CEMENT	
	1.7	Aggregate Type : Coarse	Graded Granite	
		: Fine	Natural / Manufacturing Sand	
	1.8	Free Water / Cement Ratio Specified	0.48	
2	2.1	Specified Slump (NORMAL)	**75 +/- 25 mm**	
	2.2	Maximum Aggregate Size	20 mm	
	2.3	Type of Concrete	Ordinary	
	2.4	Free Water Content	160	Kg/m3
3	3.1	Cement Content (OPC)	330	Kg/m3
	3.2	Cement Content ( )	-	Kg/m3
	3.3	Maximum Cement Content	-	Kg/m3
	3.4	Minimum Cement Content	-	Kg/m3
4	4.1	Relative Density of Aggregate	2.6	
	4.2	Concrete Density	2322	Kg/m3 (Average)
	4.3	Total Aggregate Content	1832	Kg/m3
5	5.1	Grading of Fine Aggregate	BS 882 C or M Limit	
	5.2	Proportion of Fine Aggregate	43.3%	
	5.3	Fine Aggregate Content	793	Kg/m3
	5.4	Coarse Aggregate Content	1039	Kg/m3

6 6.1 **SUMMARY – NORMAL MIX PER CUBIC METRE**

Mix (Mpa)	Slump (mm)	Cement OPC (Kg/m3)	20mm granite (Kg/m3)	Sand (Kg/m3)	Water (Kg/m3)	A/C Ratio	W/C Ratio
30N	75 ± 25	330	1039	793	160	5.55	0.48

7 **ADMIXTURES**

Mighty 85RA (RETARDAR) at	500	ml / 100 kg of OPC @	**1.7**	lit / m3
Mighty 150M (PLASTICIZER) at	0	ml / 100 kg of OPC @	**0.0**	lit / m3

8 **REMARKS**

Mix Code **: T304**

Prepared by,
Name : *Abdul Aziz Bin Haji Mukhtar*
Position : Sr. QA/QC Executive